POLICY FORUM: SPACE SCIENCE

Space Junk—Protecting Space for Future Generations

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As it sweeps through interplanetary space, Earth encounters a flux of natural debris. A meteoroid population totaling more than 200 kg of dust can be found within 2000 km of Earth. Moving faster than 20 km/s, these meteoritic bullets can inflict severe damage on artificial satellites and spacecraft, which have to be designed to avoid or withstand such impacts.

Thirty years into the space age, however, another population of debris began to have an impact on artificial satellites. Unlike meteoroids, it is man-made in origin. From satellite fragments and tools lost by astronauts to abandoned launch vehicle parts, near-Earth space is accumulating more and more junk. The space debris population now totals more than 2,000,000 kg within 2000 km of Earth (*1*) (see figure).

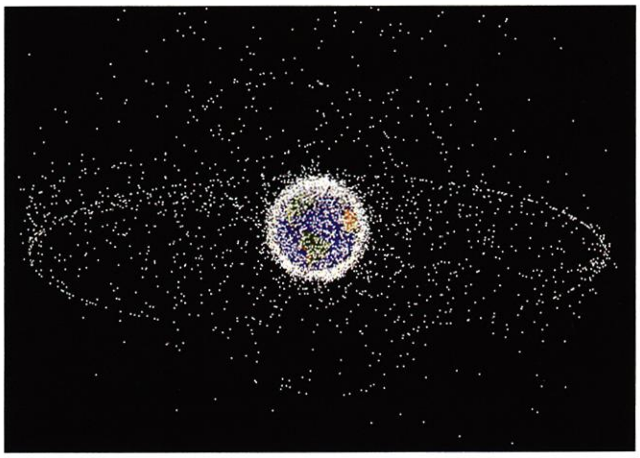
Several near-misses and one major collision involving the Cerise satellite and a fragment from an Ariane launch vehicle have alerted the community to the risks posed by this new environment, which is the direct consequence of previous launch and orbital operations. As we rely more and more on space-based systems for remote sensing, communications, and navigation, we must understand the threat that space debris poses and the long-term financial consequences of ignoring it. Further, we must take appropriate steps to ensure the cost-effective and sustainable development of near-Earth space for generations to come.

What Is Space Debris?

In its 1999 report on space debris (*2*), the United Nations Committee for the Peaceful Uses of Outer Space proposed that "space debris are all man-made objects, including their fragments and parts, [...] that are non-functional with no reasonable expectation of their being able to assume or resume their intended functions." For practical purposes, space debris is divided into three distinct populations (see the table).

Objects larger than 10 cm in diameter in low-altitude orbits and larger than 1 m at higher altitudes can be routinely detected and tracked and are known as the cataloged population. Smaller objects between 1 and 10 cm are referred to as the lethal population, because they cannot be tracked or cataloged, yet they can cause catastrophic damage when they collide with another satellite. Objects smaller than 1 cm may disable a satellite on impact but can be defeated by physical shields; they are termed the risk population.

Cataloged objects make up 99% of the mass of debris in orbit. They include payloads, rocket bodies, operational debris, and fragmentation debris. For example, launch vehicles tend to leave their upper stages behind. Smaller objects such as lens covers, separation mechanisms, interfaces, and shrouds are released during satellite injection or temporary operations during a mission. Objects are also thrown away or dropped during manned missions. The glove dropped by astronaut Ed White during a space walk from Gemini 4 in 1965 has since returned to Earth.



Earth surrounded by space debris.

These large objects are relatively easy to avoid because their orbits are tracked regularly. However, each of them may break up and generate millions of fragments. The cataloged orbital population is therefore monitored closely. As of June 2001, 170 major fragmentations had been recorded. Fragmentation may be caused by an accident such as propulsion malfunction (Ariane final stage 1986-019C), deliberate action such as a weapons test (USA 19 1986-069A), or self-destruction (Cosmos 1866 1987-059A). The 10 largest fragmentation events based on the number of cataloged fragments still in orbit (*3*) as of 1 January 2000 generated an average of ~150 cataloged debris fragments each. The top five events are all breakups of rocket bodies, produced by the high-intensity explosion of the propellants that remain on board once a payload has been delivered to orbit. To avoid future accidental breakups, studies will seek to identify the cause of each observed fragmentation and to propose appropriate mitigative action for future launches, such as the venting of residual fuel or pressurants (*4*).

Only objects in low-altitude orbits will return to Earth naturally through the influence of aerodynamic drag, which steadily reduces their orbital energy until capture by, and burn up within, the atmosphere. Atmospheric density decreases exponentially with altitude, so that above 1000 km, objects remain in orbit for hundreds or thousands of years, a legacy for future generations to deal with. Of particular concern is the failure of many operators to remove their defunct satellites a safe distance from the geostationary ring (an altitude of 36,000 km at which a satellite will orbit the Earth at the same rate that the Earth spins on its axis). Exploitation of this orbit avoids the need for Earth dishes to track the transmitting satellite, a major economic factor in the success of satellite systems that broadcast TV direct to subscribers' homes via fixed antennas. The geostationary ring has unique characteristics, and provision of such communications services from other orbits may not be viable should the ring become crowded with discarded satellites that remain on the ring indefinitely.

Assessing the Hazard

Space debris is dangerous because of the high collision velocities that are encountered (an object must travel in excess of 8 km/s to remain in orbit below 1000 km). A small coin traveling at 10 km/s through space will have the same impact energy as a small bus traveling at 100 km/h on the ground. Debris smaller than 0.01 cm primarily causes surface erosion and pitting. Secondary effects could be induced discharge of plasmas into sensitive elements of a spacecraft, triggered by the original impact. Debris larger than 0.1 cm may cause structural damage to the satellite; the severity of the impact depends on its location, the vulnerability of the system design, and pro-

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tective measures that are used. It is impractical to shield against objects larger than 1 cm in diameter (corresponding to a mass of 1.5 g and a kinetic energy equivalent to a .22 caliber bullet fired from a rifle). A collision between two satellites would result in their catastrophic fragmentation.

Objects returned from space by the Shuttle Transportation System (STS) of the U.S. National Aeronautic and Space Administration (NASA) bear evidence of the hypervelocity collisions encountered while in orbit, often involving the vaporization of the impactor, and provide clues to the nature of the particulate environment (both man-made and natural) in certain orbits. The 151 m^2 surface of NASA's Long-Duration Exposure Facility (LDEF) was covered with more than 30,000 craters visible to the naked eye; 5000 of them had a diameter larger than 0.5 mm.

POPULATIONS OF ORBITAL DEBRIS

Population	Size	Number of objects	Percent number	Percent mass
Cataloged	>10 cm	>9000	<0.1%	>99%
Lethal	1@10 cm	>100,000	<1%	<1%
Risk	0.1@1 cm	>35,000,000	>99%	<0.1%

The probability that an operational satellite will be struck by space debris depends on the satellite's trajectory, the flux of debris encountered along that trajectory, its residence time in orbit, and its projected area to the debris flux. The consequence of impact depends on the characteristics of the encountered debris flux (size, velocity, material) and the design of the spacecraft. In one extreme case of vulnerability to debris impact, the tether of the Small Expendable Deployer System-2 was severed by just one particulate impact along its length, resulting in the loss of the payload and raising questions about the use of single-strand tethers in space.

Reducing the Threat

Two courses of action are possible to reduce the hazard from space debris (*5*). The first is to manage the collision risk by accepting that the frequency of occurrences will increase but configuring systems to limit the consequences of such encounters. The second is to manage the collision hazard by reducing the threat posed by space debris by limiting the likelihood of collision in the near term.

The threat to systems currently in orbit can only be reduced through managing the collision risk. For example, the flight orientation of a vehicle may be modified to reduce its vulnerability: Orienting the STS Orbiter with its underside pointing to space and the nose in the opposite direction to travel protects the cargo bay areas and cockpit windows.

After modeling the space debris environment, designers of the International Space Station (ISS) increased the thickness of its external skin, in an effort to prevent catastrophic crack propagation following impact penetration.

However, a substantial population (>100,000) of objects residing in orbit can be neither shielded against nor tracked from the ground. This capability gap may be narrowed by improving the capability of space systems for surviving hypervelocity impacts with projectiles greater than 1 cm in diameter. The use of available shield materials such as Nextel (effectively a bullet-proof vest for a spacecraft) increases launch mass. Another option is to reduce the size threshold of objects that can be tracked and cataloged on an operational basis to below 10 cm. This would require upgrading ground-based radar and cataloging systems to evaluate potential close approaches on an operational basis. U.S. Space Command currently maintains the catalog of tracked objects from its Cheyenne Mountain complex in Colorado Springs. Its primary role is to support U.S. space and intercontinental ballistic missile (ICBM) activities, and it only provides close approach determinations for a small number of high-risk assets such as the ISS. To provide such a space traffic management service would require that the task of augmenting the existing space surveillance system, and the associated costs, be shared equitably within the prospective user community (i.e., other governments and commercial operators).

In the longer term, better monitoring and shielding will not be sufficient. As the number of objects in orbit grows, the mass penalty represented by physical shielding would make many missions prohibitively expensive. The only cost-effective option then is to limit the number of inactive objects in orbit and thus the probability of collision (*6*).

Retrieval of most objects currently in orbit is neither economical nor feasible (e.g., they are not accessible by existing systems such as the STS orbiter or are not designed for return to Earth). The next generation of launch vehicles and satellites will need to be either removed from orbit at the end of operational life or, if this is not practicable, passivated to avoid explosive breakup. Passivation would involve the removal of any on-board stored energy at the end of operational life, such as venting of propellants or pressurants and controlled discharge of batteries. To be removed from orbit, an object would need sufficient propellant to achieve a propulsive de-orbit, unless it is operated at a low enough altitude for atmospheric drag to effect its removal. Operational debris must also be reduced by ensuring that objects such as shrouds and covers remain attached to parent bodies and that elements of separation mechanisms such as explosive bolts are retained.

The Way Ahead

The importance of managing space debris is acknowledged by all space-faring nations, as they recognize the long-term financial and legal implications of future collisions between high-value operational satellites, but no international agreement for regulating space debris exists as yet. The United Nations Committee for the Peaceful Uses of Outer Space has endorsed the action undertaken by the Inter-Agency Debris Coordination (IADC) Group to reach an international consensus on mitigation practices. The committee invited IADC to present its findings during its 2003 session. The IADC brings together technical experts from the agencies of the major space-faring nations. When it met in the UK during April 2002, it succeeded in agreeing on a series of mitigation guidelines derived from the array of existing national recommendations and standards of its participating agencies. Consensus at this level is a major step forward in managing the future evolution of the orbital environment in a fair and equitable manner. There can be a cost associated with many mitigation practices. To ensure that their application will not penalize operational competitiveness, such mitigation measures must be recognized and applied by all users of space. Endorsement by the United Nations of these IADC mitigation guidelines following their consideration in 2003 will be a further step forward in ensuring safe and cost-effective access to space for future generations.

References and Notes

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