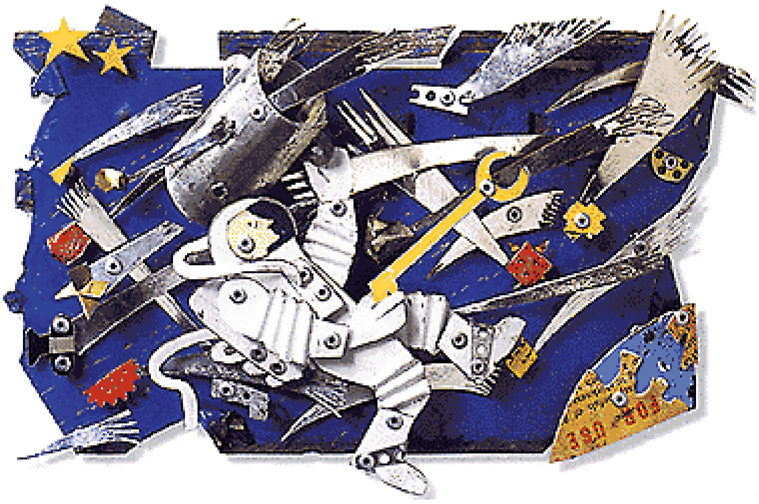
TECHNOLOGY

# The Danger of Space Junk

In a place without landfills, what goes up had better come down

STEVE OLSON JULY 1998 ISSUE





On the wall of Darren McKnight's office, in Reston, Virginia, is a display that would give pause to anyone who might be considering a trip into space: two gnarled pieces of metal shot through with shredded electrical wires and mangled rivets. They are fragments of a Navy satellite that was shattered during a test in a Tennessee bunker by a plum-sized aluminum ball traveling at a speed of about four miles per second. On McKnight's desk is a photograph showing the thousands of other pieces of debris generated by the test, which McKnight, a vice-president of a company called Titan Research and Technology, and other researchers carried out to simulate the collision of a satellite with a piece of orbiting space junk. From the photograph alone it's impossible to tell what the metal fragments might once have formed.

Everything that human beings launch high enough into space will ultimately end up like that shattered satellite. As long as an object is above the last traces of Earth's atmosphere, it will stay in orbit for thousands or even millions of years. Eventually, whether a month or a millennium after launch, it will hit one of the millions of other objects orbiting Earth. That collision will generate new fragments, like the ones in McKnight's picture, which will go whirling around the planet until they, too, are involved in collisions. Over time everything in Earth's orbit will be ground into celestial scrap.

The space shuttle *Endeavor* is scheduled to ferry the first U.S.-built component of the International Space Station into orbit several months from now. A steady stream of modules and structural elements will follow over the next five years. If the station remains in space, it will eventually collide with a piece of debris. Maybe by then the station will be empty, its human occupants having moved on to other pursuits. But maybe not. If not, here's what the astronauts can expect. If a piece of debris the size of McKnight's aluminum ball hits a pressurized module, it will rip a five-inch hole in the wall. Because of the tremendous speed at which objects in orbit move—typically about six miles per second—the collision will liquefy both the piece of debris and the wall of the module. Molten metal will splatter the inside of the module, accompanied by a flash of heat and blinding light. Air will begin streaming out the hole, leaving any surviving astronauts just a few minutes to escape. If the piece of debris is larger, the module may undergo what engineers call "unzipping": its exterior will peel away from the frame like that of a banana, spewing the contents of the module into space.

Today the risk of such a disaster for a satellite or a small craft like the shuttle is relatively low, though *Mir,* the Russian space station, launched in 1986, has been hit by objects large enough to dent the inner wall of the crew compartment. But the International Space Station, much larger than *Mir,* will be a plump target for debris. Each decade that it is in orbit, according to a recent study, the station will have about a 20 percent chance of undergoing a "critical penetration" that could kill a crew member or destroy the station—and the chances will increase as more objects are launched into space. In contrast, the chances of being in a commercial-airliner accident in the United States are about one in three million.

Venturing into space is inherently risky, and orbital debris is just one of many hazards that a space traveler faces. But the debris hazard is unique in being a product of our environmental negligence. After just forty years in space we have seriously polluted the final frontier. Valuable orbits are peppered with debris that threatens the operation of satellites and the lives of astronauts. A small group of orbital-debris experts have been concerned about this problem for years, and have slowly gained the attention of the government agencies and commercial enterprises that are now leading the way into space. Yet every four days, on average, another rocket that will make the problem worse is launched into space. According to Molly Macauley, a debris expert and a senior fellow at the nonprofit environmental organization Resources for the Future, "It's going to take a major catastrophic debris event, probably involving loss of life, before this issue gets widespread attention."

Space may seem remote, but it's really not that far away. If you could drive your car straight up, in just a few hours you'd reach the altitude at which the space shuttle flies. The popular orbits for satellites begin twice as far up—about 400 miles above our heads. The only satellites that are truly distant from Earth are the several hundred in geosynchronous orbit, a tenth of the way to the moon. There telecommunications and weather satellites orbit at the same rate that Earth rotates, allowing them to hover above a single spot on the Equator.

Since 1957 the United States and what is now the former Soviet Union have conducted about 4,000 space launches (the launches conducted by all other countries and international organizations combined account for just a few hundred additional forays into space). The leftovers from these launches—used-up satellites, the rockets that carried the satellites aloft, equipment from aborted scientific experiments—form a sort of orbital time capsule, a mausoleum of space technology. In 1963 the Air Force released 400 million tiny antennas about the size of needles into orbit in order to see if radio waves would bounce off them. Though communications satellites soon made the antennas obsolete, they still float in lethal clumps 1,500 miles overhead. In 1965 the astronaut Michael Collins lost his grip on a camera while on a space walk. Many spacecraft shed debris—bolts, lens caps, equipment covers, thermal blankets—the way children shed toys. A series of Soviet nuclear-powered spy satellites are leaking coolant into space that is congealing into balls about an inch in diameter. Even the paint on spacecraft has a tendency to erode in the harsh environment of space, creating a cosmic grit that now pelts everything in orbit.

Many of the objects released into space in the lowest orbits, like Collins's camera, have fallen back to Earth. The upper atmosphere, where the space shuttle flies, gradually slows objects down; they re-enter the atmosphere and burn up within a few months or years. But a few hundred miles higher the atmosphere is so thin that it is ineffective for cleanup. Spacecraft that are launched into orbits at this height will stay in space indefinitely. "We and the Russians have been putting stuff up there for more than thirty years, and it's just where we left it," says Nicholas Johnson, the head of the orbital-debris program at the National Aeronautics and Space Administration.

Today radars that were designed to scan the horizon for incoming Russian missiles track a silent armada of space junk instead. The U.S. Space Surveillance Network routinely follows more than 8,000 objects that are larger than four inches across, which is approximately the lower limit of detectability for current technologies.

When the network determines that the shuttle will pass within about a mile of a piece of debris, the astronauts may decide to fire the shuttle's rockets to give the junk a wider berth. But Earth's orbit also contains perhaps 100,000 objects that measure from half an inch to four inches across—objects too small to see on radar but large enough to cause a spacecraft to fail. They are the land mines of space, undetected until something crosses their path.

Especially troublesome are pieces of the more than a hundred rockets and satellites that have exploded in orbit. At the end of their useful lives spacecraft typically contain some fuel left over from launch or from orbital maneuvers. The fuel tanks deteriorate over time or are punctured by debris. The leftover fuels mix together and explode. In the worst case on record the explosion of a European Ariane rocket produced more than 500 pieces of debris big enough to disable a spacecraft.

It was the explosions of derelict rockets that first drew NASA's attention to debris. In the 1970s Delta rockets left in orbit after delivering their payloads began blowing up. An investigation by McDonnell-Douglas, their manufacturer, showed that the bulkheads separating the leftover fuels were probably cracking as a result of the rocket's passing in and out of sunlight. NASA began recommending that leftover fuels be burned at the end of a flight, or that they be vented into space. Since then most public and private launchers have taken similar measures—such steps are relatively inexpensive means of limiting debris. Still, every few months on average an old rocket or satellite explodes, flinging a cloud of debris into space.

Eventually the number of explosions will diminish, but by then spacecraft will be breaking up for another reason. As more objects go into orbit, spacecraft will begin colliding with—and being shattered by—debris. Furthermore, collisions beget more collisions. This process is known as collisional cascading, or the Kessler effect, after Donald Kessler, recently retired from his post as the head of the debris program at NASA. In the 1970s Kessler showed mathematically that once a certain amount of mass, known as the critical mass, is put into a particular orbit, collisional cascading begins even if no more objects are launched into that orbit. Originally dismissed as a mathematical fantasy, Kessler's prediction is on the verge of coming true. In the most popular orbits, Kessler says, "if we're not at the critical mass, we're pretty close to it."

Debris researchers argue vigorously about whether collisional cascading has begun. Technically, a "cascade" begins only when a piece of debris formed in one collision causes a subsequent fragmentation—an as yet undocumented occurrence. But no one disputes that space is becoming a more dangerous place. Two years ago an old piece of an exploded rocket hit the boom of a French communications satellite, sending the satellite tumbling (though ground controllers eventually stabilized it and got it working again). A Minuteman missile launched last January blew up just as it passed a piece of space debris, though the explosion could have happened for unrelated reasons. Whenever an old satellite or rocket breaks up for no apparent reason, suspicion focuses on debris.

Once collisional cascading begins, the number of objects in a particular orbit will gradually increase—and the risk to satellites and manned spacecraft will rise accordingly. A team of researchers in Italy, collaborating with Alessandro Rossi, a research fellow at the National Research Council of Italy, has calculated that enough objects are already present in two popular orbits, about 600 miles and 1,000 miles overhead, for cascading to begin. By the time the cascades have run their course, in a hundred years or so, even small spacecraft will suffer damaging collisions after just a few years in orbit. "This is only a projection," Rossi says, but if we keep putting objects into orbit as we have been, "operations will not be possible anymore."

For many years NASA and the Department of Defense were skeptical about the dangers of space debris. The problem seemed abstract, residing more in computer models than in hard experience. And it challenged the can-do mentality of space enthusiasts. Earth's orbit seemed too large and empty to pollute.

To its credit, NASA has long maintained a debris-research program, staffed by top-notch scientists who have persisted in pointing out the long-term hazards of space junk even when the higher-ups at NASA haven't wanted to hear about it. Then came the *Challenger* accident, in 1986. NASA officials realized that their emphasis on human space flight could backfire. If people died in space, public support for the shuttle program could unravel.

Engineers took a new look at the shuttle and the International Space Station. Designed in the 1970s, when debris was not considered a factor, the shuttle was determined to be clearly vulnerable. After almost every mission windows on the shuttle are so badly pitted by microscopic debris that they need to be replaced. Soon NASA was flying the shuttle upside down and backward, so that its rockets, rather than the more sensitive crew compartments, would absorb the worst impacts. And engineers were adding shielding to the space station's most vulnerable areas. At this point the modules should be able to survive impacts with objects measuring up to half an inch across, and NASA is developing repair kits for plugging larger holes in the walls.

But adding shielding and repair kits won't solve the real problem. The real problem is that whenever something is put into an orbit, the risk of collision for all objects in that orbit goes up. Therefore, the only truly effective measure is a process known as deorbiting—removing objects from orbit when they reach the end of their useful lives. With current technology deorbiting requires that a satellite or a rocket reserve enough fuel for one last trip after its operations are finished. With enough fuel a spacecraft can promptly immolate itself in the atmosphere or fly far away from the most crowded orbits. If less fuel is available, it can aim for an orbit where atmospheric drag will eventually pull it to Earth.

The logic behind deorbiting has been inescapable since the beginning of the Space Age, yet it has just begun to penetrate the consciousness of spacecraft designers and launchers. In 1995 NASA issued a guideline saying that satellites and the upper stages of rockets within 1,250 miles of Earth should remain in orbit for no longer than twenty-five years after the end of their functional lives. But the guideline applies only to new spacecraft and can be waived if other considerations prevail. As a result NASA and the Defense Department also continue to leave the upper stages of some of their launch vehicles in orbit, partly because existing designs do not lend themselves to deorbiting.

Furthermore, the character of the Space Age is changing. Of the eighty-nine launches that took place worldwide last year, almost half carried commercial communications satellites. The private sector now puts more payloads into orbit than do NASA and the U.S. and Russian militaries combined. A score of communications companies in the United States and other countries have announced plans that will put hundreds of satellites into orbit over the next decade. Many will fly in relatively low orbits within a few hundred miles above where the space station will orbit, so that they can relay signals coming from hand-held phones.

None of these companies is under any obligation to limit orbital debris. Companies that are launching large constellations of satellites are worried about collisions between the satellites, and they are well aware that a public-relations disaster would ensue if a piece of a shattered satellite smacked the station. As a result, some plan to deorbit satellites at the end of their useful lives. But other companies are leaving their satellites up or are counting on atmospheric drag to bring them down.

Government regulations covering orbital debris are still rudimentary. For now, the federal agencies that have authority over commercial launches are waiting to see if the private sector can deal with the problem on its own. But deorbiting rockets and satellites is expensive. A satellite could keep operating for several additional months if it didn't need to reserve fuel for deorbiting. Some industry representatives say they want regulations, but only if the regulations apply to everyone and cannot be evaded. "Industry has a vested interest in keeping near-Earth orbit amenable to their continued operations," Nicholas Johnson, of NASA, says. "But companies want to make sure that everyone plays by the same rules."

International regulation will be even more difficult. Already the Russians and the Europeans launch a significant number of U.S. commercial satellites. U.S. launch companies would howl if the government imposed unilateral restrictions on spacecraft launched from U.S. territory. Extending restrictions internationally would probably require the involvement of the United Nations, which would raise a host of additional issues about the equitable use of orbits. Though discussions are taking place at a technical level, no one expects international agreements on deorbiting to be achieved anytime soon.

Human societies have done plenty of things that we or our descendants may someday regret. At the beginning of the Atomic Age we seriously polluted vast tracts of land that will take many billions of dollars to clean up. We have increased the amount of carbon dioxide in the atmosphere despite a scientific consensus that global temperatures are rising as a result. We have dammed great and beautiful rivers even though the resulting reservoirs are filling with silt that will in time drastically reduce the dams' usefulness.

One reason for our nonchalance is that new technologies have gotten us out of many past scrapes—and maybe they will with orbital debris, too. Perhaps a future spaceship will race around Earth grabbing old spacecraft and flinging them back into the atmosphere, though it is hard to imagine a similar clean-up method for the small pieces of debris generated by collisional cascading. Maybe Star Wars technologies will produce a laser that can shoot orbital junk from the sky.

But no such technologies are available today. Two years ago a distinguished National Research Council committee concluded that "active removal of debris will not be an economical means of reducing the debris hazard in the foreseeable future." Even if some such technology were developed, it would probably be much more expensive than reserving a bit of fuel to bring a spacecraft down at the end of its functional life.

In 1987 the World Commission on Environment and Development defined sustainable development as meeting the needs of the present generation without compromising the ability of future generations to meet their needs. In space we are failing the sustainability test miserably. A hundred years from now, when our descendants want to put satellites into orbits teeming with debris, they will wonder what we could have been thinking. The simple answer is we weren't thinking at all.

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