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Mars laboratory lands on red ink

Space debris: A growing challenge

A conversation with Graham Love

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SPACE DEBRIS

A growing challenge

Remnants of on-orbit collisions, exploded spacecraft, and defunct satellites now greatly outnumber active space assets. Looming objects have already caused orbiting vehicles, including the ISS, to make evasive maneuvers. Experts are assessing the risks and their implications for future space programs. If steps to mitigate the problem are not taken soon, say some, portions of near-Earth orbit could become unusable for the foreseeable future.

Take a long look into the clear night sky. There is no doubt that the wonder of it all is overpowering. But also take note that you are eyeing Earth's largest junkyard—a dumping ground for dead and dying spacecraft, spent rocket stages, lens caps, paint chips, and, yes, even a lost-to-space tool bag.

The U.S. Space Surveillance Network is tracking more than 19,000 Earth-orbiting man-made objects larger than 10 cm (4 in.) in diameter. Roughly 95% of this number represents some form of debris. But there are also an estimated 300,000 additional objects in Earth orbit measuring 1-10 cm across, along with many millions smaller than 1 cm.

Slipping through space at high speed, even a half-inch-wide piece of debris hitting a spacecraft can have devastating effects.

While all this clutter might be out of sight, it is hardly out of mind. Take for example the February collision between a defunct Russian Cosmos spacecraft and a commercial Iridium satellite. That crash added significantly to the number of bits and pieces already circling the Earth. The accident meant, for instance, that ESA's ERS-2 and Envisat missions were 30% more likely to face a catastrophic impact from space debris.

Two years earlier—again compounding an already terrible situation—was China's destruction of its inactive Fengyun-1C weather satellite. That January 2007 antisatellite target practice by China produced a debris cloud, a messy aftermath described as the most prolific and serious fragmentation in 50 years of space operations. Those leftovers from the test are likely to remain in Earth orbit for centuries, affecting the ability of satellite operators to steer clear of on-orbit collisions. Indeed, in June 2007 NASA reported maneuvering its $1.3-billion Terra satellite to avoid a piece of Fengyun-1C debris.

More recently, ISS crew members took refuge in a docked Soyuz spacecraft to avoid a piece of space flotsam that could have struck the station. The ISS itself has been maneuvered several times to avoid debris.

These and other past incidents constitute a wake-up call.

Domino effect

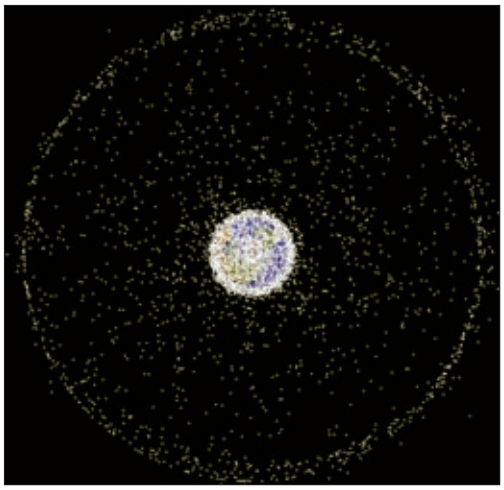
Answering that call are insurers gauging the risks posed by debris and mulling over premium increases, legal scholars reviewing the many liability issues associated with orbital collisions, and policy specialists studying the need for a new set of decrees to deal with debris and assessing the implications for future space programs.

Orbital debris "is the gravest threat to new and existing space systems." That is a view shared by two RAND experts, Caroline Reilly, a research assistant working on defense strategy and planning, and Peter Zimmerman, former chief scientist for the Senate Foreign Relations Committee and a former State Dept. science advisor. They cite the sheer volume of debris and the lack of any mechanism for cleaning it up, factors enhancing the odds that more orbital junk, if left unchecked, may render portions of space temporarily or permanently unusable.

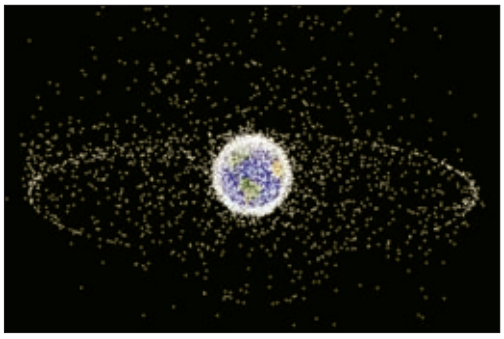
Reilly and Zimmerman have singled out work done decades ago by Donald Kessler and Burton Cour-Palais, NASA space debris experts who concluded that without the means to remove debris, the amount of litter in more densely populated orbits would reach a critical point. Beyond that tipping point, they said, a collision between two objects of sizable mass could spur a space "domino effect"—now known in some circles as "the Kessler syndrome"—that is, each shrapnel cloud would collide with more satellites, creating subsequent impacts and more debris, until that region of space becomes, in effect, a cloud of tightly packed junk.

LEO is the most concentrated area for orbital debris.

by Leonard David
Contributing writer



NASA's GEO polar images are generated from a vantage point above the north pole, showing the concentrations of objects in LEO and in the geosynchronous region.



This NASA image was generated from a distant oblique vantage point to provide a good view of the object population in the geosynchronous region (around 35,785 km altitude). Note the larger population of objects over the northern hemisphere is due mostly to Russian objects in high-inclination, high-eccentricity orbits.

If a surge of collisions started in the geostationary belt, say Zimmerman and Reilly, "it is possible the entire belt would be closed for business, permanently."

Nicholas Johnson, NASA's chief scientist for orbital debris, testified in April before the House subcommittee on space and aeronautics at a hearing called "Keeping the Space Environment Safe for Civil and Commercial Users." Putting the situation in perspective, he said, "While the adage 'what goes up must come down' still applies in the space age, most satellites take a very long time to fall back to Earth. In many cases, this descent can last hundreds, even thousands, of years. Consequently, after more than 4,600 space missions conducted worldwide since Sputnik 1, a large number of human-made objects have steadily accumulated in Earth orbit."

Johnson pointed out that the numerous operational satellites now circling the globe, as well as the human-occupied ISS, are accompanied by a far greater population of obsolete spacecraft, dilapidated launch vehicle orbital stages, intentionally discarded refuse, and the wreckage of more than 200 satellite explosions and collisions.

"The threat posed by orbital debris to the reliable operation of space systems will continue to grow unless the sources of debris are brought under control. The international aerospace community has already made significant strides in the design and operation of space systems to curtail the creation of new orbital debris, but more can be done," said Johnson.

Space situational awareness

Today, space system operators receive space situational awareness (SSA) data principally from the DOD Commercial and Foreign Entities program, Johnson testified in April. "Enhancements to this program, both to serve a larger number of users and to increase the variety of services available, especially conjunction assessments, offer the greatest near-term and lowest cost improvement to space safety. In the longer term, technical advances in space surveillance, including more capable sensors and higher accuracy data, are likely needed."

Lt. Gen. Larry James, commander of the U.S. Strategic Command's Joint Functional Component Command for Space, testified at the same hearing. He called space traffic growth both a challenge and a concern.

"In 1980 only 10 countries were operating satellites in space. Today, nine countries operate spaceports, more than 50 countries own or have partial ownership in satellites, and citizens of 39 nations have traveled in space. In 1980 we were tracking approximately 4,700 objects in space; 280 of those objects were active payloads/spacecraft, while another 2,600 were debris. Today we are tracking approximately 19,000 objects, 1,300 active payloads, and 7,500 pieces of debris. In 29 years, space traffic has quadrupled," James noted.

James told lawmakers that based on the past 10 years of launch activity, a conservative estimate projects that the number of active satellites will jump from 1,300 to 1,500 over the next decade. Depending on the effectiveness of future sensors, the overall number of tracked objects could increase from 19,000 to as many as 100,000, he testified.

Ensuring safe operations

James said this year's Iridium/Cosmos collision provided "an excellent example" of the relationship the U.S. military has with commercial users, and of what is being done to ensure safe space operations. This seemed an odd choice of words given his follow-on comment that the Joint Space Operations Center began increased conjunction assessment screening of Iridium assets 4 hr 50 min *after* the conjunction. The center now screens more than 330 objects daily to ensure safe

spaceflight operations for both DOD and commercial space users supporting DOD missions, he added.

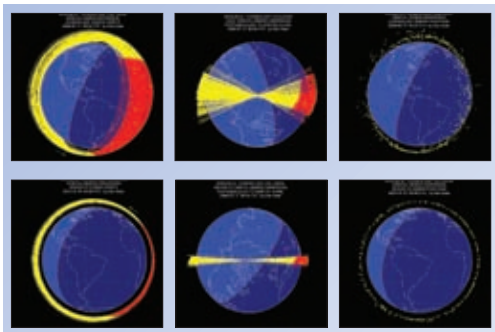
"The U.S. space surveillance architecture currently detects and tracks thousands of objects, but critical gaps remain in an ability to fully track and characterize all on-orbit objects, analyze and predict conjunctions," James said. A key program to address this gap, he continued, is the "Space Fence," foreseen as the most accurate dedicated radar in the U.S. Space Surveillance Network, hardware that could provide critical coverage from the southern hemisphere.

The Space Fence would be capable of performing 750,000 observations each day and would track over 100,000 objects, thereby reducing coverage gaps and greatly improving space situational awareness at both LEO and MEO. In addition, James underscored the future fielding of the Space-based Space Surveillance satellite, which will enable an uninterrupted scan of the entire GEO belt every 24 hours—a marked improvement over present-day situational awareness of assets at that altitude.

Also testifying at the hearing was Richard DalBello, vice president for legal and government affairs at Intelsat General, which operates an armada of more than 50 satellites—the largest geostationary commercial fleet assembled to date. He stressed that the U.S. government should play a leadership role on the issue of space traffic control.

At present, satellite operators count on the U.S. government to monitor hardware such as dead satellites and other objects that are drifting in geostationary orbit and could collide with an active satellite. DalBello said, "The safety of commercial space activities can be ensured only if there is a commitment from the U.S. government, and other governments equipped with the same type of radar or optical observation capabilities, to monitor uncontrolled space objects and to alert commercial operators, in real time, of the risks of collision with their operational satellites." Adequate funding for SSA—the ability to monitor and understand the constantly changing space environment—is key, he added.

"It would be extremely valuable if satellite operators and governments could find a way to share their collected data in an organized, cooperative fashion. Such a sharing process could result in the creation of a 'Global Data Warehouse' for space information," DalBello observed. He also spotlighted the space debris guidelines developed by the Inter-Agency Space Debris Coordinating Committee, an intergovernmental body created to exchange information on space debris research and mitigation measures.



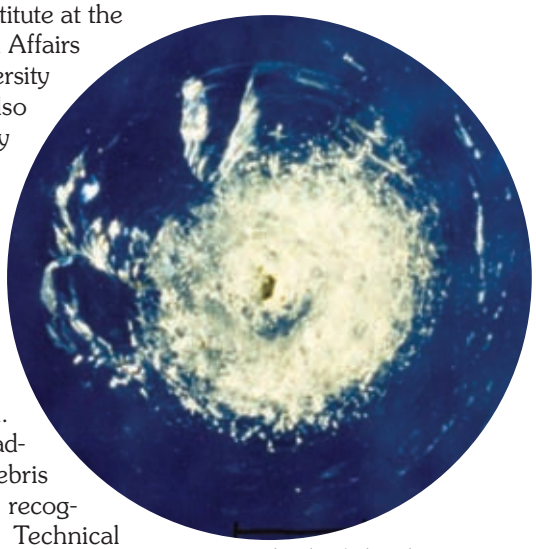
The Iridium 33/Cosmos 2251 collision in February resulted in a great increase in the debris population. Images generated by Dan Deak.

Other nonbinding guidelines could be developed, he suggested, such as a formalization of existing rules regarding the movement of spacecraft between orbital locations; protocols for informing other operators when one of their spacecraft could potentially cause damage to other space objects; and protocols for managing the loss of control of a satellite.

"Within the next decade, many more countries will gain the ability to exploit space for commercial, scientific, and governmental purposes. It is essential that the world's governments provide leadership on space management issues today in order to protect the space activities of tomorrow," he concluded.

Sharing a similar view is Scott Pace, director of the Space Policy Institute at the Elliott School of International Affairs at George Washington University in Washington, D.C. He also testified in favor of voluntary "rules of the road" for space traffic management.

"Improving space situational awareness and reduction of the hazards posed by man-made orbital debris are both vital to the long-term sustainable use of space for all nations," Pace noted. "Spacefaring nations should adhere to consensus orbital debris mitigation standard practices recognized by the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space. Improving space situational awareness should also be regarded as a promising area of international cooperation."



Space shuttle windows have been dinged by orbital debris on many missions. Credit: NASA.

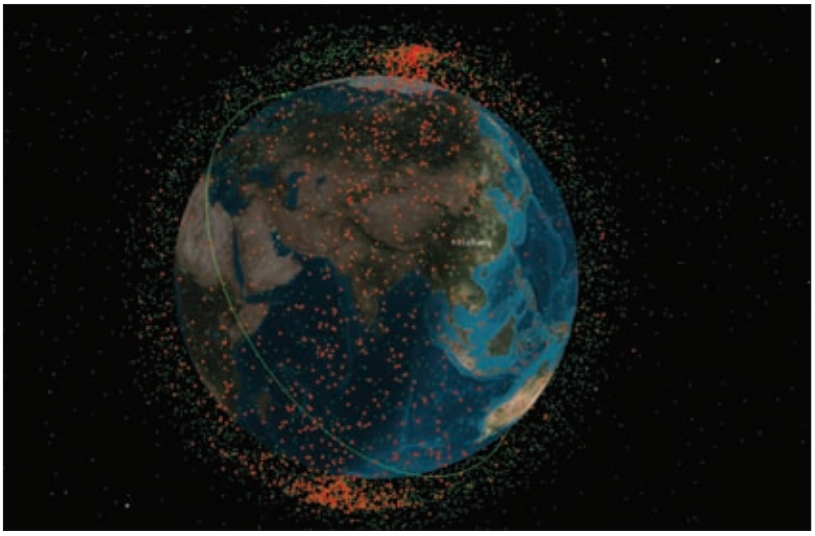
Taking out the trash

There is no question that the menace of space clutter is real. But that hazard is largely manageable, explains Johnson of NASA's Orbital Debris Program.

Johnson, a 30-year veteran of research on the subject, tells *Aerospace America* that in the past few years, the most significant advance in understanding the orbital debris environment has involved the area near the geosynchronous orbit. "NASA, ESA, and Russian sensors have detected a significant number of [pieces of] debris not yet tracked by the U.S. Space Surveillance Network."

A portion of this small (0.2-1.0-m) debris population exhibits characteristics of high area-to-mass, says Johnson. Near GEO, solar radiation pressure exerts a strong perturbing force on the orbits of such debris. This in turn affects not just the probability that one of these pieces might strike an intact satellite or rocket body, but also the consequences of such a strike.

Although there has been progress in this field, more work is needed in certain areas, notes Johnson. "Clearly, more observational data on debris in both low- and high-altitude orbital regimes is necessary to more precisely characterize the near-Earth space environment and to monitor the growth and evolution of the orbital debris population. To accomplish this, more capable and more numerous sensors—radar and optical—are required."



Screen shot from an AGI Viewer file shows a Chinese antisatellite scenario from January 2007 (5 min after ASAT test) with the ISS orbit (green line), LEO satellites (green dots), and debris ring (red). Credit: AGI/CelesTrak/CSSI.

In terms of public awareness, the debris issue—collisions, clouds of junk zipping through space, and warnings to astronauts about close calls—makes for high media attention. And there is sometimes a degree of hype in such reporting.

"There is a tendency of some, not all, media to exaggerate both the near-term and far-term threats posed by orbital debris," Johnson notes. "While the threats are real, today they are largely manageable. In addition, not enough credit is given to the scientific and operational communities for their efforts to date. The near-Earth space environment would be much worse today without the unheralded efforts of a small segment of the aerospace community during the past three decades."

Clearly, a space edict on "taking out the trash" would reduce future on-orbit collisions. "The problem is there's no cost-effective technology for doing it," says Lawrence Wein, professor of management science at Stanford University's Graduate School of Business. Enforcing existing rules that require space programs to take out their own trash, he believes, could stem the growing threat of expensive orbiting satellites colliding with space litter.

Wein contends that what is occurring in LEO mimics environmental economics here on terra firma. Like resources here on Earth, space is undergoing an early assault from human encroachment.

Wein and Andrew Bradley, a doctoral student at Stanford's Institute for Computational and Mathematical Engineering, argue for compliance with existing NASA rules requiring that objects be removed from orbit within 25 years of being launched. The two call for focusing future policy on achieving full compliance with rules for getting equipment out of orbit, and for making it taboo to blow up orbiting objects intentionally.

Another suggestion by Wein and Bradley is to set fees for every launch and penalize those who ignore their floating trash. Undoubtedly this approach would necessitate heavy political and economic negotiations, "but if we could get high compliance, this problem could stay under control," Wein believes. The fees would be used to compensate for operational spacecraft destroyed in future collisions, and partially fund R&D for space debris mitigation technologies.

A growing predicament

Space law specialist James Dunstan of the law firm Garvey Schubert Barer sees the recent Cosmos/Iridium accident as a case of first importance for space law.

Iridium carried insurance for a collision, Dunstan notes, but only for third-party damage. It is unclear whether Iridium even knew of the probability of the collision. Also, be-

Space traffic management

Reducing the threat to both human spaceflight and satellites from destructive space debris and increasing knowledge about the space environment is more easily said than done. Over the past decade and a half, the world's major space agencies have been developing a set of orbital debris mitigation guidelines aimed at stemming the creation of new space debris and lessening the impact of existing debris on satellites and human spaceflight. These guidelines are one essential part of the long-term sustainability of Earth orbit.

The collision in February between a commercial Iridium satellite and a nonoperational Russian Cosmos spacecraft underscored another essential part of this sustainability—knowledge about objects in orbit and the space environment, also known as space situational awareness.

"Space situational awareness is one of the most important space issues of our time," said Ray Williamson, executive director of the Secure World Foundation, headquartered in Superior, Colo. The group is a strong advocate for a space situational awareness system that embraces several key attributes:

•Combines data from multiple sources, including ground- and space-based sensors, satellite owner-operators, and space weather data.

•Provides a level of data for civil uses by all actors, a function that the U.S. military currently does not have the resources to provide fully.

•Mixes both unilateral solutions with international participation and engagement, potentially saving money through combining data from existing sensors owned by states all over the globe and enhancing overall security.

The optimistic message from Marshall Kaplan, a senior scientist at the Johns Hopkins University Applied Physics Laboratory, is that methods and systems for reducing the debris threat will be developed over the next several years.

The solution, senses Kaplan, will involve several efforts, including added spacecraft shielding, extra satellite onboard propellant for maneuvering, limitations on creating new debris, automated deorbiting of upper stages, mandatory end-of-life risk-reduction maneuvers, and physical removal of debris from high-threat zones.

"Success will require all spacefaring nations to cooperate and work together," Kaplan notes. Still, given these approaches, what comes next?

There must be an ongoing international program to keep debris-collision risks at acceptable levels, Kaplan suggests, a program that could be labeled space traffic management. That effort might operate on a voluntary basis in which spacefaring nations agree to limitations on populating certain orbital slots or zones.

"Each nation would furthermore have to accept the liability associated with the creation of new debris and agree to certain restrictions on orbital usage. Space traffic management would also entail the continued control of debris through an active removal program that maintains the highly used orbital regions safe for operational satellites," Kaplan says. "Ultimately, the space traffic management program may be integrated with the mainstream space program in a way that would permit new spacecraft orbit insertions and debris removal operations with every launch campaign," he concludes.

[Leonard David is a research associate with the Secure World Foundation.]

cause that particular Iridium satellite was well past its useful life, there is a question about whether the operator was hesitant to use any stationkeeping fuel to avoid the collision. Then there is the argument of the Russians, who say that customary international law does not require them to get rid of their derelict satellites. Iridium argues that it is under no obligation to take active steps to avoid the collision, says the space law analyst.

Last March, Iridium issued a postcollision statement explaining that it has been engaged for some time with the U.S. government in an effort to improve assessment and warning, through activities such as the Commercial and Foreign Entities program.

"While these have been useful efforts, Iridium believes this incident has demonstrated the need for even more aggressive action, and the company supports enhanced actions to increase the margin of safety for space operations," says the statement. A specific future activity that Iridium endorses is long-term investment to improve SSA so that the space environment can be better understood and better characterized.

"Iridium believes provision of satellite orbital data by commercial operators would relieve the U.S. Air Force of the necessity to devote resources to tracking the company's satellites, and could provide accuracy greater than would otherwise be commonly available," the statement continues, adding that improved SSA is essential to the well-being of the global space community.

"This event certainly points to the importance of SSA to the success of the commercial space industry, including the commercial and government customers served by Iridium. Iridium is committed to healthy cooperation between government, industry, and the international community to improve the capabilities of SSA and to enhance the security of the space environment for all constituents," the Iridium statement concludes.

Seeking solutions

As the quandary posed by orbital debris worsens, it is stirring some to seek remedies. One clean-up initiative is being fostered by Marshall Kaplan, a senior scientist at the Johns Hopkins University Applied Physics Laboratory in Laurel, Md. This still-embryonic effort could entail working on simulations just to an-

ticipate how bad the situation might become over the next few years, Kaplan tells *Aerospace America*, with the prospect of carrying out ground- and/or space-based experiments on how to actually collect debris. "What we have up there now is sufficiently large, small, and numerous that it's going to propagate and continue to make the problem worse."

Proposed remedies include placing in orbit a huge aerogel-laden fluff ball to snag debris, using terminator tethers, and even using low-power ground-based lasers to churn out pulses of energy directed at chunks of debris. Such energetic zaps would vaporize the surface layer of the debris, causing a thin layer of gas to blow off. This release of gas would kick the debris into a higher altitude but decrease its perigee. The targeted space junk would then reenter and burn up in the atmosphere within a couple of days.

At present, Kaplan says, the approach being taken—trying to mitigate the increase of debris—is the right one. For now, the cost of cleaning up debris in LEO is not economically workable. "It's going to be expensive…it's going to take a long time," he says. We don't have a good solution as yet. But there is coming a time when space debris reduction will become an imperative."

He speculates about one worrisome scenario: "If there were a catastrophic collision between debris and the ISS where lives were lost…I think the end result would be a discontinuation of human spaceflight, at least in low Earth orbit, until the debris problem is fixed. That would give us impetus to do something fairly soon, although you never know what the political landscape might be like."

Decluttering the valuable real estate that is LEO will require international participation, and will take the form of a major new space program, Kaplan suggests. While the time is now to blue-sky space debris reduction options, the task ahead is akin to a superfund clean-up campaign far greater than anything ever undertaken by the Environmental Protection Agency in terms of money and scope.

"This problem has gotten a lot worse," he says. "Space debris is a growth industry, that's for sure."