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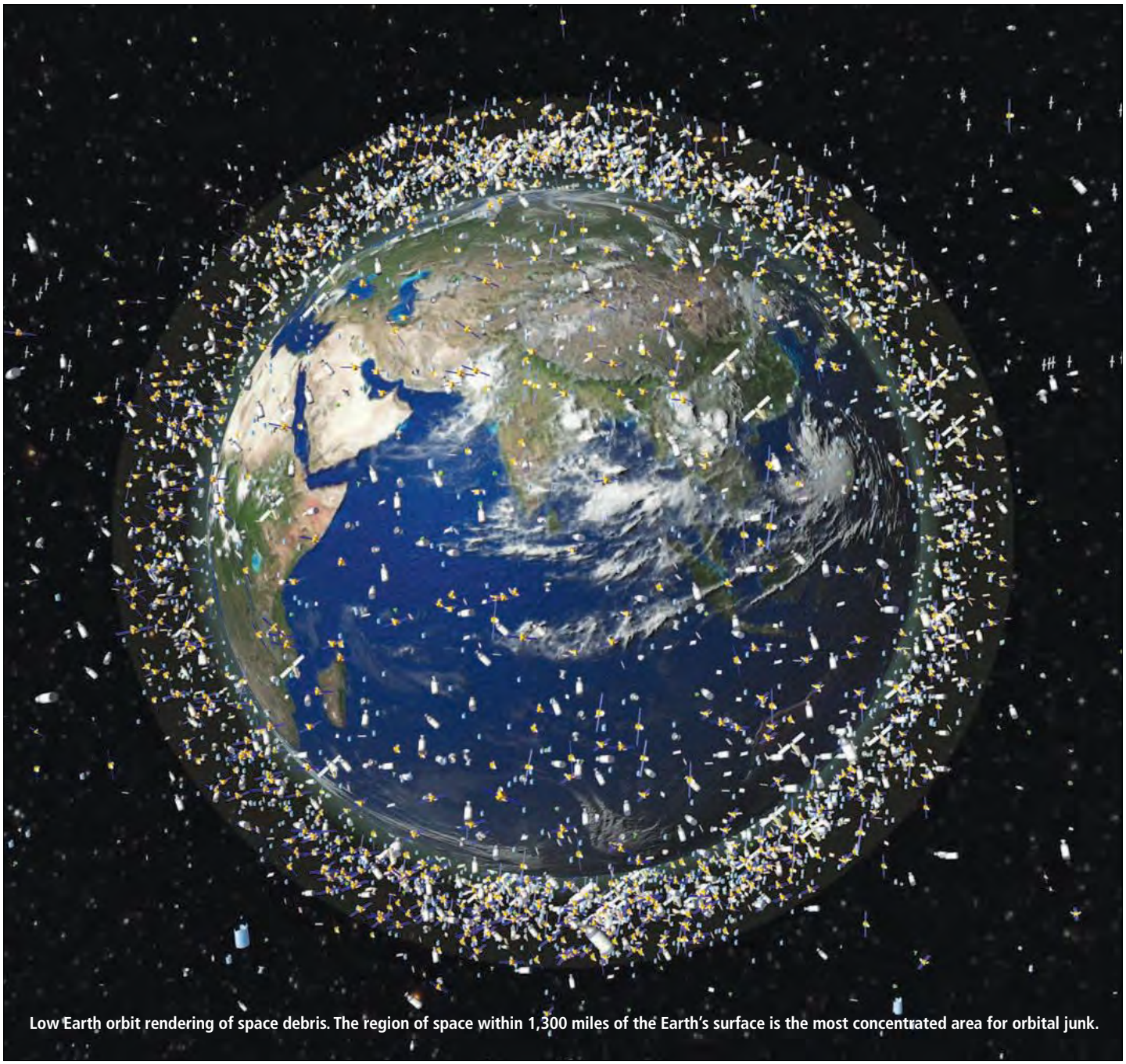
Cleaning up



Low Earth orbit rendering of space debris. The region of space within 1,300 miles of the Earth's surface is the most concentrated area for orbital junk.

European Space Agency

ACE

Once upon a time, only space wonks and those in charge of keeping the crews safe aboard the International Space Station and the shuttle orbiters worried much about space debris. The problem is fast becoming a boardroom issue, given all the new proposals to populate low Earth orbit with swarms of small commercial satellites. Even if the new satellites don't add to the junk pile, their mere presence will make space more crowded and increase the likelihood of catastrophic collisions. Debra Werner spoke to technologists about ideas for addressing the problem.

Six thousand metric tons of spent rocket stages and circuit board fragments clutter Earth's orbit amid 1,300 operational satellites, including billions of dollars of spy satellites and commercial communications, weather forecasting and scientific spacecraft. Into that mix, most of which float in low Earth orbit, entrepreneurs now hope to inject thousands of small satellites to satisfy demand for broadband Internet in remote areas.

The sheer size of these constellations has raised alarms about potential high-speed mash ups with functional spacecraft, the International Space Station or existing trash — which would create thousands of new pieces of detritus.

With that nightmare scenario on their minds, technologists are working on ideas for zapping, catching, corraling or nudging dead satellites and space junk out of the paths of functional satellites or into Earth's orbit where they would burn up. Technologists know they must work fast, because while an international rule says old satellites should be disposed of, not everyone does so. And technical solutions are just beginning to emerge for the smallest of satellites whose size just doesn't permit the thrusters

by Debra Werner
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and propellent of larger spacecraft.

In January, OneWeb Ltd., a startup backed by Richard Branson's Virgin Group and microchip-maker Qualcomm Inc., unveiled plans to send 648 satellites into low Earth orbit to deliver broadband Internet. That was followed two days later by a declaration by SpaceX CEO Elon Musk to "rebuild the Internet in space" through a constellation that eventually could number 4,025 small satellites. These projects aim to bring Internet service to the roughly half

Washington Aerospace Partnership

Internet via space: SpaceX CEO Elon Musk tells employees and supporters in Seattle about plans to launch a constellation of 4,000 satellites to deliver broadband to remote locations.

of the world's population that lacks online access. That fleet of new satellites, however, will exacerbate the hazards from space garbage. Already, the U.S. Air Force is tracking some 21,000 objects — each the size of a softball or larger — orbiting Earth with 1,300 operational satellites. Ground-based radars have detected an additional 500,000 smaller floating objects, ranging in size from one to 10 centimeters.

Launching a few small satellites would not add much to the overall debris problem, says J.-C. Liou, chief scientist in NASA's orbital debris program office at the Johnson Space Center in Houston. "But if you are talking about deploying hundreds or thousands of small satellites, then that could be a problem."

OneWeb and SpaceX insist they won't be adding to the debris collection. SpaceX's Musk, speaking at a news briefing, said his company's satellites would travel in a sparsely-populated orbit at an altitude of around 1,100 kilometers to avoid striking debris. What's more, he said, "We are going to make sure we de-orbit satellites effectively so they burn up on reentry and land in the Pacific somewhere."

Terminator tape

For at least 15 years, Rob Hoyt, chief executive and chief scientist at Tethers Unlimited, a small aerospace research and development company based in Bothell, Wash., has been promoting the idea of using tethers to pull satellites down from orbit. Hoyt in the late 1990s urged NASA and the U.S. Air Force to equip satellites with electrodynamic tethers, long pieces of conductive metal tape that would unfurl at the end of the spacecraft's mission. The tether would expand a spacecraft's cross-section to increase neutral particle drag and to generate a current as it plowed through Earth's magnetic field. Some of the satellite's kinetic energy would be converted to electrical energy, and its orbit would sink lower as it slowed and became more susceptible to gravity's tug.

Hoyt's idea made little headway at first because satellite developers weren't required to equip satellites to move out of the way or deorbit at the end of their missions. If satellites are low enough, they eventually return to Earth's atmosphere and, if they aren't too huge, burn up. Most big satellites, however, can remain in orbit indefinitely.

"We were 15 years ahead of the market with a product people didn't want to pay for," he says.

The commercial market wasn't interested at that time, but in 1995 one government agency saw the debris problem coming. NASA adopted guidelines that year requiring its own spacecraft to re-enter Earth's atmosphere or move to undesirable orbits, often called graveyard orbits, within 25 years of the end of their useful lives. In 2002, the Inter-Agency Space Debris Coordination Committee, a group that included 11 international space agencies at that time and now includes 13 members, adopted that policy.

Not everyone complies. Only about 60 percent of the satellites and rocket bodies in low Earth orbit from 2000 to 2013 were expected to re-enter or move into graveyard orbits within 25 years, according to

the 2013 report, "Mitigation Rules Compliance in Low Earth Orbit," released by CNES, the French space agency. Liou says the first step in dealing with the problem of orbital debris is to get operators to respect that voluntary deadline. "It is important for the global space community to do a better job of complying with the 25 year rule," says Liou.

For decades, large satellites have carried extra propulsion to move into graveyard orbits or return to Earth's atmosphere and burn up. Small satellite operators are just beginning to experiment with alternative de-orbiting technologies more suitable to the limited mass and volumes of their spacecraft.

In December 2012, Tethers Unlimited sold its first CubeSat Terminator Tape, a simpler, cheaper version of Hoyt's earlier product. The first CubeSat Terminator Tape, an 83-gram de-orbit module the size of a drink coaster, was purchased by the Aerospace Corp., a nonprofit based in El Segundo, California, that provides research, development and advisory services for U.S. national security space programs. The Aerospace Corp. bolted the $7,000 Terminator Tape onto AeroCube-5 and launched the spacecraft in 2013 on a mission to test on-orbit pointing and tracking technology.

Whenever AeroCube-5 completes its mission — no date has been set — it will send a 1-second signal to the spacecraft to release its 250-meter long conductive tape and provide the first space-based demonstration of the Terminator Tape, Hoyt says.

Next year, at least two additional Tethers Unlimited customers plan to launch spacecraft carrying the smaller NanoSat Terminator Tapes, a 50- to 70-meter conductive film designed to de-orbit satellites weighing 50 to 200 kilograms. The length of the NanoSat Terminator Tape varies based on the mass and orbit of its host satellite.

Surrey Satellite Technology US, the Colorado-based subsidiary of Britain's Surrey Satellite Technology Ltd., is slated to launch the NanoSat Terminator Tape in May 2016 on its Orbital Test Bed, a spacecraft with five payloads provided by academic organizations, commercial firms and U.S. government customers. In addition, leaders of the U.S. Air Force's University Nanosat Program purchased two NanoSat Terminator Tapes for use on two satellites. The NanoSat Program is a joint effort of the Air Force Research Laboratory's Space Vehicles Directorate, Air Force Office of Scientific Research and AIAA to develop a skilled workforce through support of small satellite initiatives. One of the tapes is scheduled to fly in 2016 on the Georgia Institute of Technology's Prox-1, a 50-kilogram satellite with an embedded five-kilogram cubesat. Once in orbit, Prox-1 is designed to release the cubesat but remain nearby to inspect it through the use of automated guidance, navigation and control systems. The second satellite has not yet been selected.

Surrey Satellite Technolgy

An engineer indicating the integration location of the Nanosat Terminator Tape Deorbit Module.

Drag sails

Circling overhead at this moment is another idea for deorbiting small satellites and rocket parts, this one a device called dragNET made by engineers at MMA Design in Boulder. Technicians folded DuPont Kapton polyimide film into a 2.8 kilogram box about the size of a telephone book and attached this dragNet to an experimental Air Force satellite called STPSat-3, short for Space Test Program Satellite-3. Another dragNet was installed on the Minotaur upper stage that launched STPSat-3 in 2013.

The Air Force officials confirmed that the 14-square-meter dragNET unfurled on the Minotaur after the launch, says Mitchell Wiens, MMA's president and chief operating officer. That sail is expected to bring the rocket body into Earth's upper atmo-

sphere sometime in mid-2016, less than three years after it was deployed.

When the sail on STPSat-3 springs open, probably next year, it will demonstrate dragNET's ability to work after being stored in its box for three years, Wiens says. The polyimide film is protected by a proprietary coating.

Sweeping up debris

Even if all new satellites were equipped to avoid becoming space debris once they finish their missions, that wouldn't address the junk that's already up there or the problem of satellites malfunctioning so badly that they can't be commanded.

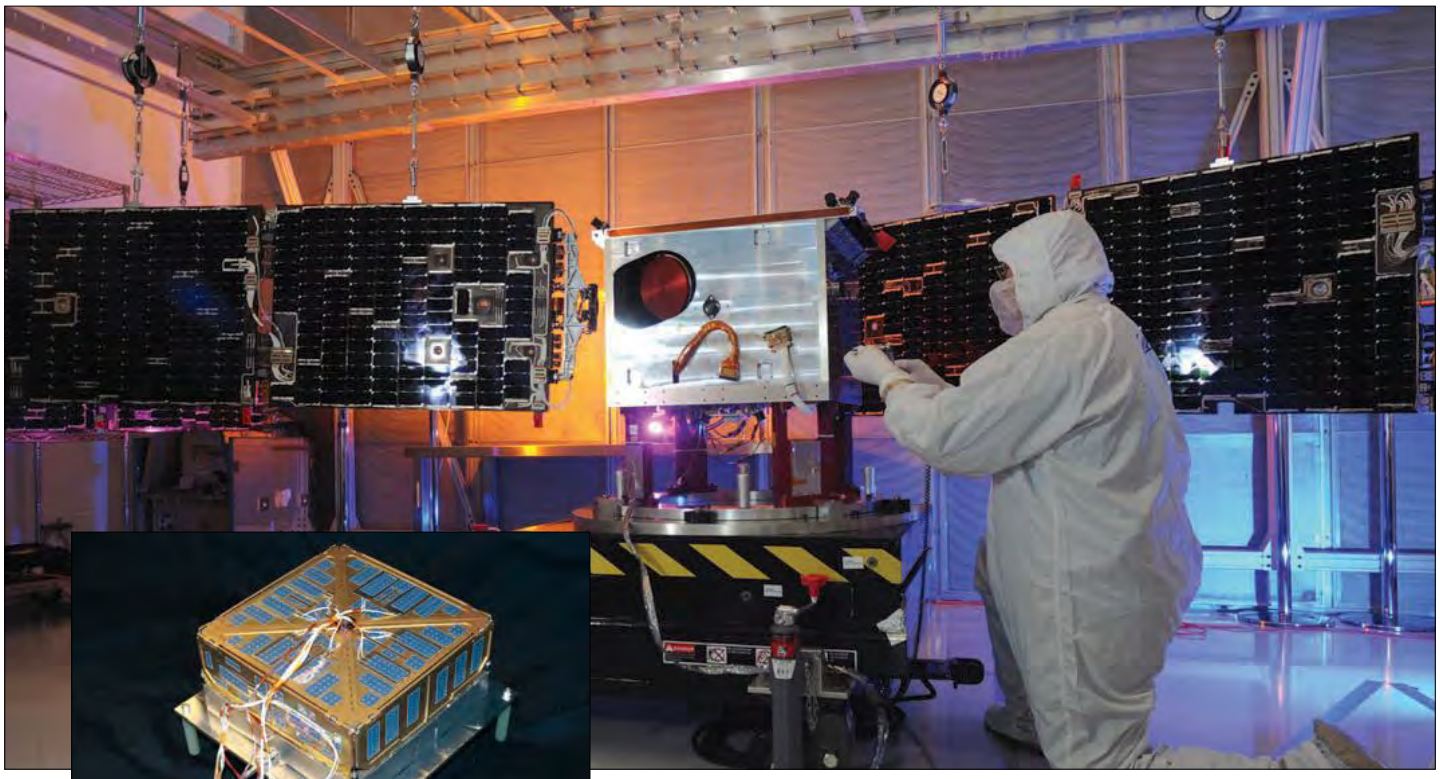
Claude Phipps, founder of Photonic Associates LLC of Santa Fe, New Mexico, suggests that the answer should be space-based lasers. With short, repetitive pulses focused on 50-gram objects, such as shards from an exploded upper stage, a laser beam could slow their momentum, bring the debris closer to earth and speed its descent into Earth's atmosphere, where all but the largest satellites burn up entirely or break apart into small pieces before reaching the ground.

Those small objects, which are difficult to track using ground-based telescopes "are like shrapnel, it's important to get rid of them," Phipps says.

For larger objects, Phipps proposes aiming laser pulses on a single object over a period of months or years. The trick would be to slow its momentum without breaking it into pieces, which Phipps says will not be a problem if the pulses are aimed at metal or other appropriate targets.

Phipps began advocating a similar campaign using a ground-based laser in 1996. That plan drew vigorous opposition from U.S. intelligence agencies, who worried that a laser beam might blind spy satellites. So Phipps began looking at options for positioning the lasers in space, where they could not accidentally shine into a downward pointed sensor.

Other industry and university teams are designing satellites to catch hold of debris. Busek Co. of Natick, Massachusetts, wants to unreel a small satellite from a larger one, and direct the smaller one to grab debris weighing more than 1,000 kilograms. The larger satellite, weighing roughly two metric tons,



Ball Aerospace

MMA Design

Installed on the Minotaur upper stage that launched the Air Force's Space Test Program Satellite-3 (STPSat-3), MMA Design's dragNET De-orbit System consists of a lightweight compact stowed thin membrane that creates the necessary drag to passively de-orbit a spacecraft or launch vehicle.

École Polytechnique Fédérale de Lausanne Swiss Space Center

Photo illustration: The Swiss Space Center at École Polytechnique Fédérale de Lausanne CleanSpace One, a project to develop and build the first installment of a family of satellites specially designed to clean up space debris.

would be called ORDER for the Orbital Debris Remover, and it would provide propulsion, power and communications for its 10-kilogram companion, called SOUL for Satellite on an Umbilical Line. SOUL would rendezvous, inspect and grab its target without human intervention. ORDER would reverse the direction of its electric thrusters and tug the debris to another orbit, where SOUL would release it. ORDER would then reel in SOUL and find its next target.

That fetch-and-relocate system won't come cheap but it could be quite busy. Busek estimates a customer would pay about $80 million to build the twin satellite system, which could make 100 trips in geostationary orbit, moving 2,000-kilogram spacecraft to graveyard orbits, or take 40 2,000-kilogram satellites out of low Earth orbit, says Dan Williams, Busek's business development director.

Astroscale, a Singapore startup that earlier this year attracted an investment of $7.7 million, wants to show how a pair of satellites and newly-developed silicon adhesive might catch debris. In 2017, Astroscale plans to launch what it calls the Active Debris Removal System, consisting of a 60-kilogram satellite shaped like a flying saucer called Mother connected to a 20-kilogram cylindrical satellite known as Boy. Once in orbit, Astroscale intends to send the Mother-Boy spacecraft toward a 50-kilogram satellite the firm also plans to launch in 2017. When Mother finds the target, which will not have navigation features to make this approach easy, it will release Boy to fly nearby and catch it with the silicon adhesive, says Philippe Moreels, the company's business development manager. Boy would fire its hydrogen peroxide-fueled solid propellant thrusters to move itself and the debris toward Earth's atmosphere, where Boy and the debris would burn up during re-entry.

If that demonstration succeeds, Astroscale's Tokyo manufacturing plant would start work on one or two Active Debris Removal Systems to launch annually. Each Mother spacecraft would be designed to launch six Boys, Moreels says.

Meanwhile, a Swiss university group is working on a technology specifically meant for snaring cubesats. The École Polytechnique Fédérale de Lausanne in 2018 plans to launch a 30-kilogram satellite called Clean Space One. The satellite would be loaded into a small spaceplane that Swiss Space Systems is designing to be launched in 2018 from the roof of an Airbus A300. The student-designed Clean Space One would approach SwissCube, a cubesat EPFL launched in 2009, fly around it to analyze its shape and tumbling motion, catch it — no one knows yet whether this would be done with claws, a cage or a net — and maneuver toward the upper atmosphere.

"Maybe by demonstrating we can clean up the little SwissCube which we put up there, we would show others how to act responsibly," says Volker Gass, director of EPFL's Swiss Space Center.