Space Debris Mitigation Technologies

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The orbital debris population and its potential for continued rapid growth presents a significant threat to DoD, NASA, commercial, and international space endeavors. Recent studies at NASA/JSC have indicated that the population of debris in LEO is now so large that it will continue to increase for over 50 years even if no new objects were to be launched into orbit. Other studies have indicated that unless strong mitigation measures are adopted, the density of orbital debris particles in LEO will soon become large enough that collisions between them will lead to exponential growth of the number of debris particles, which could make both manned and unmanned activities in space unacceptably risky.

Fortunately, NASA, the DoD, FCC, and other relevant authorities have begun to respond to the orbital debris problem by placing requirements for debris mitigation upon new space systems. Examples of these requirements are the DoD Instruction 3100.12, Sec. 6.4, “Spacecraft End-of-Life” and NASA’s Safety Standard (NSS) 1740.14, “Guidelines and Assessment Procedures for Limiting Orbital Debris,” which specify that stages, spacecraft, and other payloads should be disposed of at the end of mission life by one of three methods: atmospheric re-entry, maneuver to a designated storage orbit, or direct retrieval. If these mitigation measures are implemented and adhered to over the coming decades, the growth of the debris flux can be reduced from an exponential growth curve down to a logarithmic growth curve, as illustrated in Figure 1. Figure 1 also shows that if active measures are taken to remove existing large debris, the debris flux could actually be reduced.

TUI Debris Mitigation Technologies
Tethers Unlimited, Inc. (TUI) is working to develop technologies to reduce the population of space debris by addressing both the challenge of preventing creation of debris by new spacecraft and the challenge of removing existing space objects.

Deorbit Modules
To enable cost-effective end-of-mission disposal of spacecraft, TUI is working to develop and qualify several ‘deorbit modules’ that will provide fully-autonomous end-of-mission deorbit capability for LEO spacecraft with very low mass and cost impacts to the spacecraft program.

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2. NRC Committee on Space Debris, Orbital Debris: A Technical Assessment, 1995, p 166.
Terminator Tape™

For spacecraft massing less than 1 metric ton and operating at altitudes less than 850 km, TUI’s “Terminator Tape” module will enable the satellite system to comply with 25-year post-mission orbital lifetime requirements with extremely low mass and cost impacts. The Terminator Tape module is a pizza-box shaped unit, 30 cm x 30 cm x 2.5 cm, which mounts to any surface on the spacecraft. The module’s mass is less than 3 kg. Solar cells can be mounted to the top surface of the module if desired. Upon activation, the module deploys a several-hundred meter long conducting tape. This tape has a proprietary construction that enables it to generate not only aerodynamic drag as it passes through the upper atmosphere, but also electrodynamic drag through passive interactions with the space plasma and the Earth’s magnetic field. The electrodynamic drag greatly enhances the orbital decay compared to an aero-drag only device, deorbiting the host spacecraft within the required 25-year period, as illustrated in Figure 3. The Terminator Tape is not reliant on power from the host spacecraft, so it can deorbit spacecraft that have malfunctioned. Once the module is fully qualified, TUI anticipates offering flight units at a cost of less than US$100,000, providing a truly cost-effective debris mitigation capability.

Figure 2. Form factor for the Terminator Tape Module.

Figure 3. Predicted altitude profile for a 400 kg spacecraft deorbiting from an 830 km Sun-synchronous orbit using a Terminator Tape module.
Terminator Tether™

For spacecraft massing more than 1 metric ton, operating at altitudes above 850 km, or requiring very fast deorbit (within a few weeks or months, rather than years), TUI has been working for over a decade to develop and test a “Terminator Tether” module that will utilize active electrodynamic drag to rapidly deorbit LEO spacecraft. A prototype of a Terminator Tether unit sized to deorbit a 3 metric ton spacecraft from LEO within several months is shown in Figure 4, and a ‘nanoTerminator’ unit sized to deorbit a 1-3 kg CubeSat is shown in Figure 5. This device bolts to the host spacecraft, and remains dormant until it is time to deorbit the spacecraft. Upon activation, the Terminator Tether module kicks itself away from the host spacecraft, deploying a several-kilometer long conducting tether. The motion of the tether through the Earth’s magnetic field will cause a voltage to develop between the ends of the tether. The system incorporates technologies that enable the tether to make electrical contact with the conducting plasma in the ionosphere, enabling a current to flow up the tether. This current in turn interacts with the Earth’s magnetic field to produce a drag force on the tether system that rapidly lowers the orbit of the spacecraft over a period of several months until it burns up in the upper atmosphere. The Terminator Tether module will typically mass 1-2% of the mass of the host spacecraft, a significant mass savings compared to the 5-20% mass allocation required for using thrusters to deorbit the spacecraft. Because the tether system can utilize the currents and voltages generated by the tether to power itself, it is not reliant upon power from the host spacecraft, and thus can deorbit spacecraft that have malfunctioned.

Figure 4. Terminator Tether device for 2-3 metric ton LEO satellites.

Figure 5. The ‘nano-Terminator’ module is designed to deorbit CubeSats and other nanosatellites within 25 years.

Figure 6. The Terminator Tether deorbits a spacecraft by generating drag through interactions between currents in the tether and the Earth’s magnetic field.
Capture of Space Debris: The GRASP Technology

To address the challenge of limiting growth of debris due to explosions and collisions of the dead spacecraft and upper stages already in orbit, TUI is also working to develop a technology called “Grapple, Retrieve, And Secure Payload” (GRASP), which will enable small spacecraft to capture space debris objects in order to deorbit or otherwise dispose of them. As illustrated in Figure 7, the GRASP technology uses lightweight inflatable booms to deploy a large net structure, which can be maneuvered around a space debris object and then collapsed to securely capture the object. The GRASP system is lightweight and simple, enabling it to be carried on small spacecraft, even nanosatellites, and it can be used to capture objects that are tumbling or do not have the convenient grappling fixtures required by robotic arm based capture systems. After capture, a deorbit system such as a Terminator Tape could be used to dispose of the debris. A prototype mounted on a nanosatellite bus is shown in Figure 8, and images from a successful test in zero-g are shown in Figure 9. TUI envisions the GRASP technology serving a role in an “Orbit Sweeper” system that would deploy multiple nanosatellites into an orbital region to collect and deorbit space debris, enabling new spacecraft to operate more safely at that altitude.

Figure 7. TUI’s GRASP technology will enable small spacecraft to capture space debris objects for deorbit or disposal.

Figure 8. 1.5 m GRASP prototype integrated into a 3-U Cubesat bus.
Figure 9. TUI successfully demonstrated capture of a tumbling object by the GRASP prototype in a microgravity environment on a Zero-G Corp. aircraft.