SPACE DEBRIS: HOW THE UK IS TACKLING SUSTAINABILITY BEYOND THE EARTH

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As evidenced by COP28, major undertakings are in progress to mitigate climate change and achieve a net-zero future on Earth. Sustainability beyond Earth is equally critical for protecting the space ecosystem and continuing to benefit from space-enabled economic growth and prosperity. This article directs readers to the growing space debris problems, their serious threat, and how the UK addresses this global challenge.

INTRODUCTION

The first documented case of an accidental collision between two artificial objects in low Earth orbit (LEO) occurred in 1996. The incident happened on 24 July when debris from an Ariane launcher hit the French military reconnaissance satellite CERISE. It is a sadly repeating story. In February 2009, the collision between the US satellite, Iridium 33, and the derelict Russian Cosmos 2251 resulted in more than two thousand pieces of debris.

In October 2016, a retired satellite from the US Air Force, the Defense Meteorological Satellite Program Flight 12, broke up in orbit. More recently, in March 2021, the breakup of Chinese satellite Yunhai-1 was linked to an accidental collision with a small piece of debris just 10-50 centimetres in length associated with a Russian Zenit-2 launcher sent into orbit in 1996.

These events and many others have created more than 27,000 tracked pieces of debris orbiting the Earth and an estimated tens of thousands of pieces of smaller debris that remain unchartered. The sizes of space junk vary from a few millimetres, such as glass fragments, to several meters, such as the large non-operational Environment Satellite (ENVISAT) by ESA.

Natural meteoroids are also space debris. Yet, regardless of whether debris is natural or artificial, it poses a significant threat to our current and future space assets.

LITTERED ORBITS

In Earth's orbit, most debris results from orbital collisions and breakups from space missions. The more waste there is in space, the greater the risk to operational satellites and crewed

vehicles, such as the International Space Station (ISS) and SpaceX's Crew Dragon capsule, or directly to astronauts undertaking extra-vehicular activities.

Now, after 66 years of uncontrolled debris proliferation and intensive space use, Earth orbits have reached a tipping point, known as the "Kessler syndrome", where human intervention is needed. The Kessler Syndrome is a runaway chain reaction of collisions in orbit that exponentially increases the number of debris in orbit (See essay: 'Recognising the Threat of Space Debris' by Donald J. Kessler.) It is a grim prospect.

LOSING ACCESS TO SPACE

A forecast for the next 200 years states that access to space will become impossible if measures to mitigate debris proliferation are not in place. Many space agencies are working on solutions to combat the threat of space junk, especially in developing different methods for removing the trash in Earth's orbit.

However, Active Debris Removal (ADR) missions are complex, expensive, and high risk due to the extreme space conditions and the limited technology readiness levels. As a result, there are no viable and cost-effective 'one-size-fits-all' solutions for ADR, as the strategy depends mainly on the debris object's size, shape, and operational state.

Nevertheless, capturing and deorbiting large derelict objects in widely used orbits, such as LEO, remains a priority because larger objects are larger targets, so the risk of colliding with other orbit objects is higher. Beyond LEO, high-value satellites occupy valuable orbital slots in medium Earth orbit or geostationary orbit. These, too, must be protected by removing the faulty ones that represent a threat.

Handling cooperative and uncooperative targets in orbit poses different types of challenges. The detailed strategy for capturing space debris depends on several factors. If the target is spinning or tumbling, the chaser spacecraft must match this movement, making the approach and capture difficult. It increases the risk of the grappling manoeuvre going wrong.

DEBRIS CAPTURE TECHNIQUES

Despite the many difficulties in removing debris from orbit, progress is being made. The Surrey Space Centre led the RemoveDebris study funded by the European Commission. As part of the technology demonstration mission, the spacecraft was taken to ISS and deployed into orbit in 2018. This mission successfully validated the space net and harpoon technologies developed by industrial partners.

More recently, in March 2021, Astroscale launched its ELSA-d spacecraft to demonstrate capturing cooperative orbital debris using a magnetic capture mechanism to retrieve and deorbit a target spacecraft designed by Surrey Satellite Technology Ltd. While a success, this technique is not suitable for capturing satellites that do not have the pre-designed counterpart of its magnetic docking mechanism.

ROBOTS TO THE RESCUE

Businesses are turning to space robots to offer the kind of versatility needed for general-purpose ADR missions; space robots are satellites with robotic arms and hands to manipulate debris. Semi-autonomous and autonomous space robots are preferred to overcome the time delays encountered in Earth-based teleoperation. ADR missions are fertile testing grounds for artificial intelligence and machine learning algorithms in space.

Over the years, various space agencies, industries, and academic research groups have studied mission concepts to validate the use of a space robot for ADR missions. However, for various reasons, none made it into orbit.

ESA's e-Deorbit study aimed to capture the largest piece of space debris in orbit – ENVISAT. Ultimately, the scale of the mission worked against the demonstration as deorbiting ENVISAT was seen as rather ambitious with 2018 levels of technology. The knowledge acquired feeds into ESA's current efforts to remove space debris.

In 2019, ESA signed an €86 million contract with a European industrial consortium led by Swiss start-up ClearSpace SA to develop a unique debris removal service to remove the VEGA Secondary Payload Adapter

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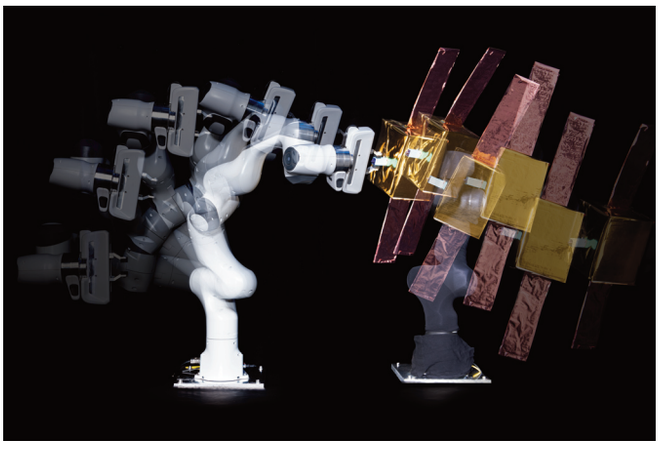

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These photographs by Max Alexander demonstrate active debris removal from space: (a) Portrait of Professor Dr. Rai inspired by Michelangelo's 'Creation of Adam' (b) Robotic ADR - it shows the sequences involved in capturing uncooperative space debris (target on the right) using a spacecraft with a robotic manipulator (chaser on the left). This Earth analogue experimental testbed at the University of Lincoln is used for validating the close-proximity approach, safe capture and controlling the worst-case tumbling behaviours of the debris for post-capture stabilisation and subsequent deorbiting. Thank you to Dr. Mithun Poozhiyil and Dr. Manu Nair for building the robotic ADR testbed.

launched in 2013. The ClearSpace-1 capture system under development consists of four articulated robotic arms large enough to embrace the target.

Astroscale's Cleaning Outer Space Mission through Innovative Capture (COSMIC) mission, due for launch by 2026, aims to dovetail their rendezvous and proximity operation and robotic debris capture capabilities to remove two defunct British satellites currently orbiting Earth.

UK LEADERSHIP IN SPACE SUSTAINABILITY

The UK space industry is actively engaging with stakeholders and policymakers to assess plans and ambitions outlined in the National Space Strategy published by the government in September 2021.

The UK government and the UK Space Agency are facilitating the co-creation of new finance and insurance products with international space agencies, industries, investment bankers, insurers, underwriters, regulators, legal advisors, and other stakeholders. The collective effort will help establish a global framework for the commercial space sector to mitigate the creation of new debris, clean up legacy space junk, and invest in in-orbit services.

A major step to realising sustainability beyond Earth is prioritising large-scale cleaning up of space junk from LEO as a service. To position the UK at the forefront of space sustainability, UK-based satellite manufacturers and operators must adhere to evolving space regulations and adopt modular architecture for newer satellites to facilitate in-orbit servicing, life-extension, and subsequent removal, upcycling, or recycling. The best practices in the UK space sector are being shared with other like-minded countries, encouraging businesses to follow safety standards.

The unveiling of the Astra Carta by HM The King in June 2023 and signing up to the Memorandum of Principles by over 120 companies is strong evidence of the UK's commitment to space sustainability. The Earth and Space Sustainability Initiative funded by UKSA further reinforces the importance of a robust regulatory framework and standards for sustainability in space.

OUTREACH AND BUILDING PUBLIC AWARENESS

An important component for the continued success of the UK's space sustainability effort is public awareness. The photography series, *Our Fragile Space*, by Max Alexander highlights the urgent need to become good stewards of the near-space environment as the number of satellites grows exponentially. This limited and fragile environment is becoming congested with megaconstellation satellites, rocket bodies and space debris.

The photographs capture the importance of space in our daily lives, showing the socio-economic and scientific benefits and anthropogenic change of how humans are polluting the land, oceans, atmosphere, and now, this fourth domain of space.

The project involved engaging with the space sector, agencies, military, financial and insurance markets, academia, government and regulators. The series also explores the global efforts to address this challenge, including the UK's leading role in active debris removal and the emerging field of space sustainability.

The exhibition has helped 'galvanise space policy for the UK government' and has been shown at prestigious venues such as Lloyd's of London, the United Nations, the European Parliament, and the New York Stock Exchange.

CONCLUSION

In summary, building debris removal and satellite servicing capabilities will open bigger and longer-term markets linked to the assembly of high-value infrastructures, upcycling and recycling of space debris, and manufacturing in space. The UK is well positioned to steer this new 'in-orbit economy'. As it evolves, robotics and autonomous systems will be pivotal in many future ADR and on-orbit serving, assembly and manufacturing missions. In turn, safer and sustainable use of space will boost economic prosperity and improve lives on Earth. ■