LEVERAGING FLEXIBILITY TO CREATE

# CIRCULAR SPACE ECONOMIES

Madeline Bowne | 2025 SGx Lightning Talk

## THE SPACE ENVIRONMENT

Satellite Launch Surge

**24,500 satellites** projected to launch between 2022-2031, driven by low launch costs, flexibility of LEO megaconstellations, and demand for space-based services [1, 2]

Environmental Impact of Launching & Deorbiting

Rocket and re-entry emissions deplete ozone and contribute to climate change through pollutants like alumina, black soot, NOx, CFCs, and CO2 [2, 3, 6]

Solution

Transitioning to multi-use satellites could reduce congestion and mitigate atmospheric pollution

Circular Economy

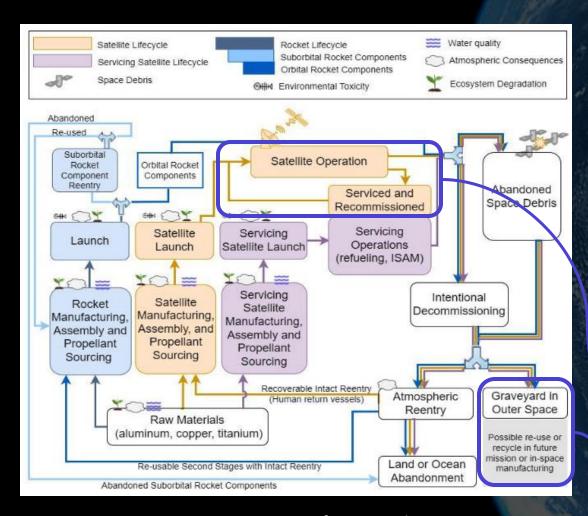
Orbital Congestion

LEO traffic worsened by megaconstellations, increasing collision risks [3]; **de-orbiting within 5 years is the accepted best practice** for LEO satellite disposal [4,5]

Atmospheric Changes

Anthropogenic cooling and resulting atmospheric contraction **could extend orbital lifetimes**, heightening collision risks [7]

## WHAT ARE CIRCULAR ECONOMIES?



"A circular economy uses a systems-focused approach that is restorative or regenerative by design to enable resources to maintain their highest value for as long as possible." [8]

**EPA Definition** 

On-orbit servicing is a critical capability for establishing circular space economies

Aerospace Corporation Figure for Circular Space Economies [8]

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### ON-ORBIT-SERVICING

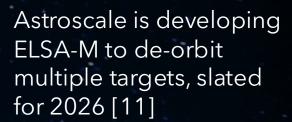


D-Orbit is developing their General Expansion Architecture (GEA) to provide life-extension services in GEO. Credit: D-Orbit [10]

Present and developing OOS vehicles focus on servicing satellites in GEO

The cost and benefits of OOS in LEO, aside from ADR, don't add up

Northrop Grumman Space Logistics provides on-orbit servicing in GEO with their MEV and MRV (below) [9]



### HOW TO INCENTIVIZE OOS IN LEO?

It's a necessary capability for circular space economies in LEO, but how could it be more attractive to the private sector?

Concept of Operations

## **Key Differences for OOS in LEO vs. GEO**:

- Proliferated configuration
- Environmental factors like J2 nodal precession and drag
- Inefficient out-of-plane maneuvers

The (CONOPs) must address the distinct operational environment and constellation configuration

#### Business Case

- Constellation operators value cost, coverage, and flexibility
- Build upon advantageous sparing strategies, such as spare warehouses in parking orbits [12]
- OOS can provide value to operators through flexibility [13-16]

#### Policy

- Government intervention could promote sustainable practices in LEO
- Heavy-handed interventions could hamper space industry growth or promote "forum-shopping"
- Policies can assist, but shouldn't be the only solution

### HOW TO INCENTIVIZE OOS IN LEO?

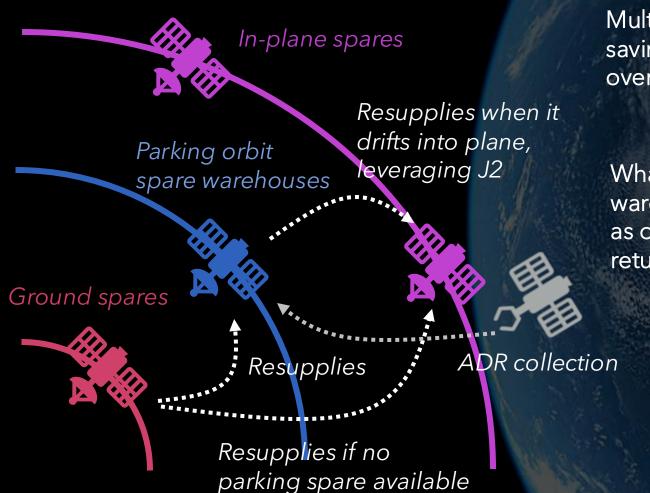
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Tailoring OOS CONOPs for LEO Focusing on constellation operator needs

Leveraging Flexibility



## BETTER CONOPS, BETTER BUSINESS CASE



Multi-Echelon Spare Strategy proposals offer cost savings for constellation operators compared to overpopulation or direct resupply

What if this concept is expanded to give the spare warehouses a dual purpose; housing spares as well as old, collected satellites that could be serviced or returned to Earth in the future?

#### **Enabling technology/capabilities:**

Reusable Second Stage

ADR Vehicles

RPOD

Multi-Echelon Sparing Strategy [12]

### FLEXIBILITY FRAMEWORKS

Leveraging uncertainty to add value through flexible mechanisms and strategies



25 de Abril bridge in Lisbon, Portugal

Built with option to support 4 car lanes and a railway on the lower platform [17]

Today, the bridge has 6 car lanes and 2 rail tracks. This strategy deferred additional costs until there was a need for extra capability, leveraging the time value of money (lowering NPV).

HCSC Building in Chicago, Illinois

Built with possible additional 27 original stories for future vertical expansion [18]

They opted to complete the second phase when personnel needs increased faster than expected

In their flexibility framework analysis, de Weck et. al. determine that Iridium losses in the late 90s could have been 30% lower if they used incremental deployment, a classic flexibility strategy [19]





### PARKING ORBIT WAREHOUSES ENABLE FLEXIBILITY

Parking orbit warehouses that store spares as well as old satellites are flexible **mechanisms** that enable several options, such as...

> Parking orbit warehouse

Collect old

sats

There are many sources of uncertainty in the space industry, like demand for services, technology obsolescence, or launch costs... that's why flexible options have value



Upgrade the warehouses to provide service such as refueling or repair



After resupplying a warehouse with spares, a reusable second stage could return the collection of satellites back to Earth

> Earth-based satellite servicing could inspire operators to make their satellites more easily refuelable or repairable in orbit



Deorbit collected satellites in a controlled manner



Major take-aways

Making OOS in LEO more attractive to the private sector requires appealing to satellite operators' needs and leveraging J2 drift for more efficient maneuvering

Several capital-intensive infrastructure projects in other industries have found success using flexibility frameworks to leverage uncertainty - the space industry could learn from these examples

Parking orbit warehouses build on a good idea and offer flexible options that could help incrementally build a more sustainable system while reducing satellite constellation operators' exposure to risk

CIRCULAR SPACE
ECONOMIES

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