Unveiling the Potential of Cooperative Multi-Agent Spacecraft for ADR, IOS, and Cyclic Space Economy

Authors

Marek Gebura
CTO @ Space scAvengers

Marc Niezette
Domain Manager for In-Orbit Servicing
@ Telespazio

Co-authors

Tomas Balog
CEO @ Space scAvengers

Michal Mlaticek
CIO @ Space scAvengers

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Why COMAS?

- Future of space exploration and exploitation depend on the development of in-orbit robotic capabilities for tasks such as **servicing** and **refueling** satellites, **transporting cargo**, **removing orbital debris** and its **recycling**, or **construction** and **maintenance** of new orbital assets.

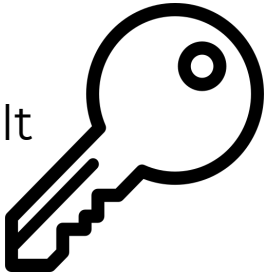
- **Docking, capture, and manipulation** of objects in orbit are key enablers for these capabilities towards cyclic economy in space.

- **Using today's single space manipulator systems with low autonomy and universality for servicing limits the advancement of the mentioned key tasks.**

ADR, IOS, and STS based on swarms of small spacecraft with various specialized functionalities acting as coordinated agents

COperative Multi-Agent Spacecraft COMAS

- Distribution of functions for completing tasks
- Stronger robustness and fault tolerance [no single point of mission failure]
- Collaborative perception for enhanced GNC and safety
- Lower costs and greater economic advantages
- Applicable for complex missions



Cooperation towards future with COMAS

SPACE SCAVENGERS

- Startup founded in 2021, winner of Slovak Space Incubator competition; incubated in Slovak Business Agency and Slovak Academy of Sciences
- Active in two ESA PECS projects focused on definition of COMAS for ADR, and key technology for IOS – CCDS Welding for In-orbit and Lunar applications
- Discussing impact of COMAS on European Future Transportation Systems with ESA
- Primary business orientation to **highly autonomous GNC for COMAS based on collaborative perception, Machine Learning and Artificial Intelligence**

Effective and Safe Spacecraft Swarms and Fleet Management

TELESPAZIO
a LEONARDO and THALES company

- One of the **leading operations and ground segment providers in Europe**
- Extending ground infrastructure and operations capabilities with the objective to provide support to a large portfolio of **IOS missions and applications**
- **Artificial intelligence for automation and autonomous operations on-board and on-ground** is a major technology that is integrated with first priority in the Telespazio infrastructure.

Other key partners

Institute of materials and machine mechanics
Slovak Academy of Sciences

SLOVENSKÁ sporiteľňa

SLOVAK SPACE OFFICE

Orbit Recycling

esa

POLITECNICO MILANO 1863

REDWIRE

STAM
MASTERING EXCELLENCE

PRVA ZVARAČSKÁ, a. s.
FIRST WELDING, Inc.
KOPČIANSKA 14, 851 01 BRATISLAVA 5, SLOVAK REPUBLIC

AStroS solutions

COMAS - Swarm of Agents

COMAS Swarm
Organized in Fleets in a Business Interesting Orbits

Scouts
To inspect and help on GNC

Dockers
To dock to a prepared target

Detumblers
To decrease tumbling rate

Vultures
To attach to unprepared target

Tuggers
To secure thrust and fuel for transfer

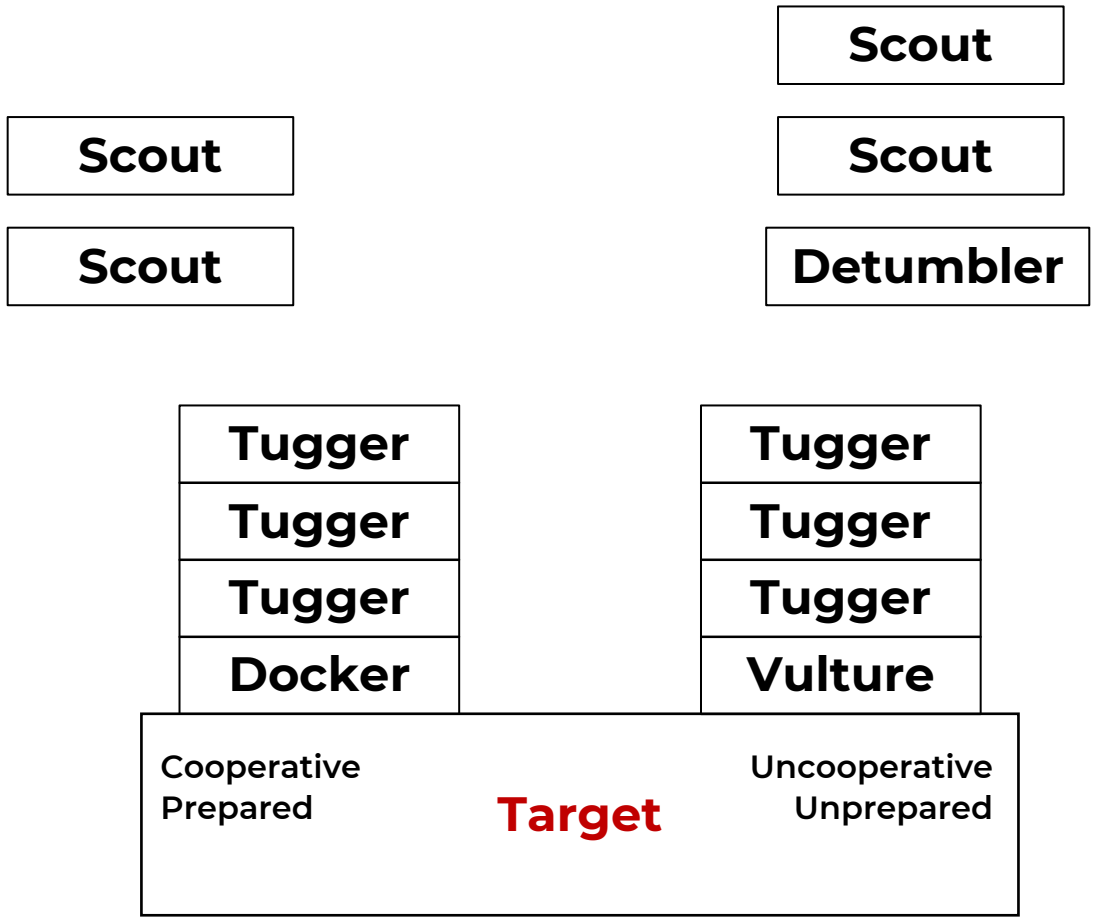
Fleet XY
Any other roles, e.g. refueling, repairing,...

Selected Key Functionalities:

- **Launchable in rideshares**
- **Ability to form stacked configurations**
- **Reliable inter-Agent communication**
- **Collaborative GNC**
- **Formation flying and collision avoidance**
- **Autonomy in Ground-Space delay-risky operations**
- **Prepared for refueling**

contract

Swarm SQUAD
Mission/Service specific



Space Scavengers Mission 1

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esa -> PECS

SK6_06 Contract 4000137299
Formulation and Assessment of Multi-Agent Active Debris Removal Application

ESA Technical officer: Robin Biesbroek
ADRIOS Mission Performance and Modelling engineer

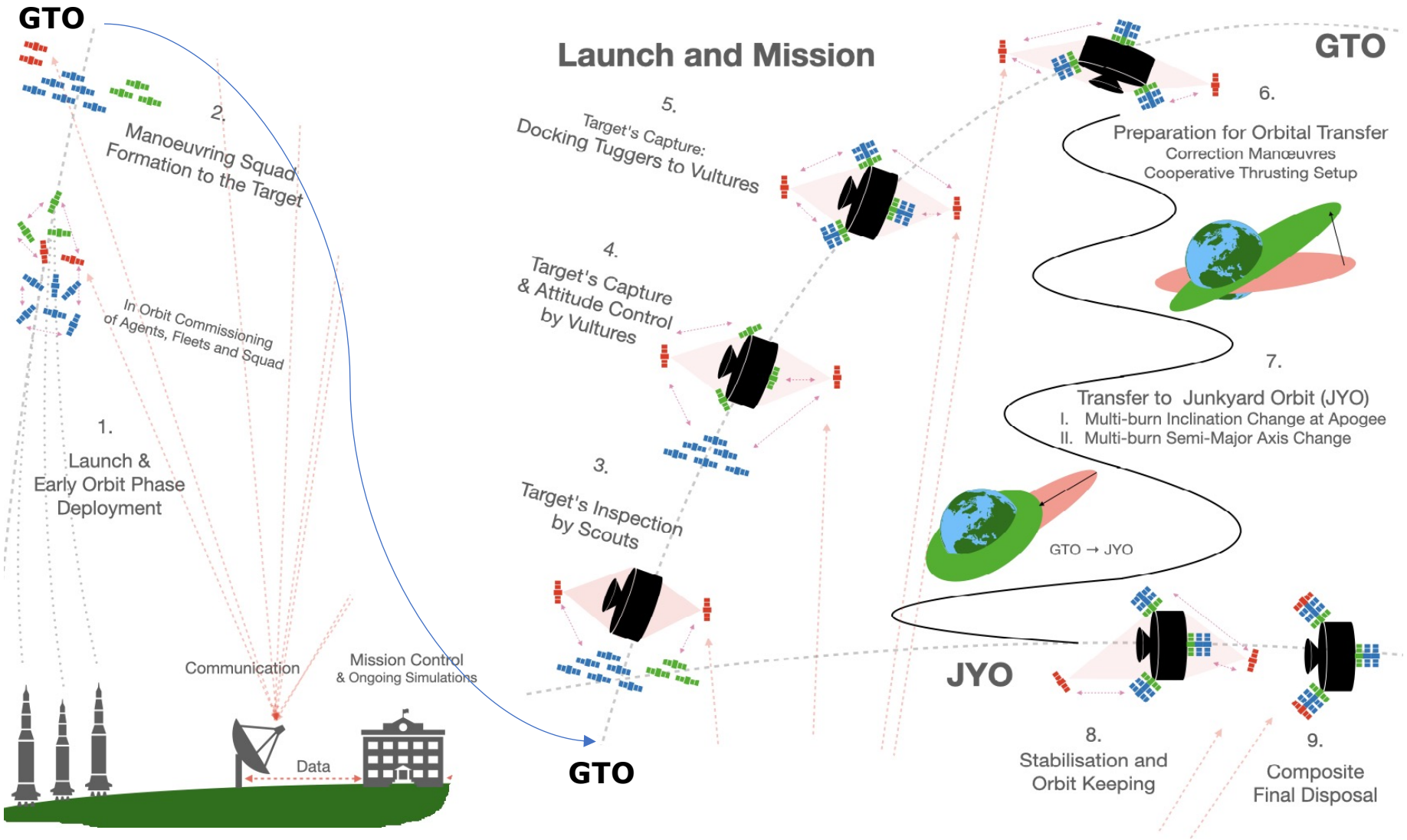
Mission Statement

The SAM-1 aims to be the world's first **swarm AD-Repositioning mission** with a goal to demonstrate the flexibility of the swarm approach for ADR, particularly for the cooperative, mainly autonomous inspection, mating, capture, and repositioning of selected European uncooperative debris from a business interesting orbit to a junkyard orbit chosen.

- ✓ **Mission Statement**
- ✓ **Concept of COMAS product**
- ✓ **Concept of Business Model for ADR**
- ✓ **Identification of Business Interesting Orbit for ADR [GTO]**
- ✓ **Identification of Target**
- ✓ **Identification of Junkyard Orbit [MEO]**
- ✓ **Detailed CONOPS + Feared Events Analysis**
- ✓ **System architecture**
- ✓ **Technical requirements**
- ✓ **Tradeoffs for key systems**
- ✓ **Key technologies + development roadmap**
- - **Deterministic simulation of the Mission [in progress]**

-> MDR (01/24)

SAM-1 CONOPS



Legend

Fleets

- Scouts
  Agents focused on target's inspection and visualisation
- Vultures
  Agents specialised in capture of an unprepared object
- Tuggers
  Agents securing higher ΔV for orbital transportation

Swarm Squad: 2x 3x 6x

- Target - EPS L9
- Ground Infrastructure
- Orbits
- Target Scanning
- Ground-Squad Communication
- Inter-Agent Communication
- On Ground Communication

Managed Space Junkyard

Concept of business place for IO-Servicing and IO-Manufacturing with AD-Repositioning being a service of resources delivery

Enabling conditions

- EU Space Junkyard Directive (Junk fees for Junk owners)
- EU gives power and budget to ESA to establish

Effective AD-REP

- cheap (< few k€/kg)
- multitarget, repetitive
- target-agnostic

COMAS Junkyard Servicers

- cost effective platform
- flexible

MSJ

operated by

Space Junkyard Operator

Key role

- Disposal of the Junk for free for paying junk owners by its repositioning to safe position
- Potentially takes liability and secures nondisclosure of sensitive HW and SW
- Operation of managed Junk Constellation (resources)

Increased orbital safety

Fostered cyclic economy

MSJ's further opportunities

- Provides secure business space for other companies benefiting from aggregated resources
- Secure orbital recycling of junk and generate revenue from selling the material and parts to IOS manufacturing companies

Key Technologies [SAM-1]

Swarm	
AI-based Swarm Algorithms	Essential for autonomous coordination and decision-making within the swarm
Agent-Agent Communication	Key for inter-agent coordination and swarm synchronicity
Satellite Docking Systems	Fundamental for spacecraft servicing and collaborative operations
Iodine Thrusters	Allows efficient and compact propulsion for microsatellites
Optical Communication	Ensures high data rate communication between agents
AI-based Perception Algorithms	Crucial for environmental perception and decision-making

Ground Control	
Advanced Ground-based Optical Communication Systems	Higher data rates and improved security
Secure and Rapid Data Relay Infrastructure	Efficient and secure data transmission from space to ground
Real-time Data Processing & Analytics	Key for on-the-fly decision making and mission updates
Advanced Ground-based Telemetry Systems	Essential for detailed monitoring of satellite health and performance
Secure Command & Control Infrastructure	Required for secure and reliable mission operations

Scouts	
Rapid Data Collection Systems	Necessary for timely and efficient data gathering
Depth Perception Systems	Vital for understanding and navigating 3D environments
Surface Analysis Tools	Essential for detailed study of space debris
High-Speed Communication	Fundamental for transmitting large volumes of data swiftly
Electro-optical Sensor Systems	Necessary for detailed imaging and environmental analysis
Cooperative AI enhanced vision	Necessary for detailed attitude analysis and surface analysis of the target

Vultures	
Single Robotic Arm	Precision and control for debris capture and manipulation
Multiple Robotic Arms	Enhanced stability and flexibility for debris handling
Flexible Tentacles with Electro-adhesive Grippers	Adaptability to various debris shapes and sizes
CCDS Welding End-Effector	Key for binding and securing captured debris

Tuggers	
Strong Docking Mechanisms	Essential for securing and transporting large debris
High-Thrust Propulsion Systems	Key for moving and guiding larger space objects
Enhanced Power Systems	Required for longer missions and heavier payloads

Summary of the key points

- The implementation of COMAS can bring transformative value to ADR, IOS, IOM, and STS, much like how MAS has revolutionised other industries (e.g., autonomous vehicles, distributed energy grids)
- COMAS-based ADR service together with the concept of Managed Space Junkyard (MSJ) operated via fleets of COMAS vehicles can lead to creation of an affordable business in cyclic space economy
- The role of ESA and EU/EC is crucial for enabling ADR —a point that bears frequent repetition due to its foundational significance. The same stands for MSJ.
- Key enablers for operational COMAS include AI-driven GNC, which leverages collaborative perception, as well as ground segment preparedness for AI-operated COMAS deployments.
- The list of key technologies for operable COMAS systems identified for SAM-1 opens up a range of new business opportunities for European entities in sectors such as AI, robotics, and data analytics.

As COMAS redefines possibilities in orbit, let's hear how Telespazio is shaping the terrestrial technologies that make it all possible.

- see the presentation titled: "Extending Ground Segment Products for supporting a large range of In-Orbit Services"

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Thank you for attention

marek@spacescavengers.sk

You can see this presentation thanks to the help of our research partner – IMSAS

IMSAS is now also contracted by ESA for a feasibility study in Contact Capacitor Discharge Stud (CCDS) Welding technology for IOS and Lunar applications with Space scAvengers as a subcontractor.

Institute of materials and machine mechanics
Slovak Academy of Sciences