DOI: 10.13009/EUCASS2025-607

The emergence of an Active Debris Removal Market and its impact on future space operations

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Abstract

The exponential growth of the space sector has led many to anticipate the emergence of an Active Debris Removal Active Debris (ADR) market. However, regulatory uncertainty, limited economic incentives, and operational fragmentation limit its development. Using the INSIDeR System as a case study, this paper examines how ADR solutions could transform future space operations by making debris removal a standard element of any space mission. In addition, this paper explores the key enablers and conditions to create and sustain an effective ADR ecosystem.

1. Introduction

The accelerating pace of global space activities has highlighted the importance of addressing long-term orbital sustainability. Although advancements in rendezvous, capture, and proximity operations have made ADR technologies more feasible, a viable market for these solutions has yet to emerge. This gap does not arise from a lack of technical capability but rather from regulatory uncertainty, fragmented responsibilities, and a lack of economic incentives. This section outlines the evolving context in which ADR is gaining relevance and presents the approach taken in this work to analyse both the systemic barriers and a potential pathway forward.

1.1 The growth of the space sector

Over the past decades, the exponential growth of space activity has led to a significant increase in the number of orbiting objects. As stated by the European Space Agency (ESA) in its annual space environment report, "Ever since the start of the space age, there has been more space debris in orbit than operational satellites."[1] Such a statement highlights the awareness of the increasing congestion of operational orbits, mainly due to former and/ or non-operational rocket bodies or satellites remaining in orbit after their mission and threatening future launches as well as operational spacecraft safety. The safety issues arising from the growing amount of debris in orbit are just the beginning, especially as the number of organisations involved in space activities continues to increase. Numerous startups, companies, and universities are responding to the call for space exploration, and humanity is witnessing the emergence of space industries in various countries.

Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) are becoming increasingly crowded due to their accessibility and the variety of missions they accommodate, such as telecommunication, Earth Observation, scientific research aboard the International Space Station (ISS), and student CubeSat projects, among others. The recent emergence of mega-constellations in LEO has further intensified orbital traffic, raising safety concerns and the risk of collisions. Looking forward, other applications, such as in-orbit services and commercial space stations, will introduce new and more complex objects into already congested orbits, aggravating concerns related to the safety and sustainability of the space environment. In particular, the fears of a Kessler Syndrome scenario, defined as a chain reaction of debris generation that could hinder future operations in space.

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1.2 Why ADR is gaining attention

Policies and legislation have been gradually evolving to manage the issue of space debris, compelling operators to plan for the end-of-life of their spacecraft as a preventive measure to mitigate this growing problem. As a result, operators are encouraged to include additional propellant in their spacecraft to enable controlled re-entry at the end of their mission or to travel to a graveyard orbit, freeing up space for new-generation satellites.

While these measures reduce the generation of new debris, they do not help mitigate the risks posed by older, non-operational orbital objects, such as rocket bodies like the Ariane 5's EPS, which are among the most hazardous debris. To avoid collisions with such dangerous objects, operators must rely on Space Situational Awareness (SSA) methods and plan Collision Avoidance Manoeuvres (CAM), which are becoming increasingly frequent. This situation results in a higher workload for engineers, who must conduct extensive collision risk analyses. Moreover, there are implications for spacecraft design, including the need for shielded structures to withstand impacts from small debris and additional embedded fuel to perform the necessary CAMs to protect the mission from potential loss.

To tackle this problem and lighten the burden of space operators once in orbit, ADRSolutions are becoming more and more investigated. These solutions typically involve In-Orbit Servicing (IOS) spacecraft designed to remove space objects that can no longer manoeuvre on their own. This concept consists of approaching and capturing the targeted debris using various methods, such as harpoons, robotic arms, magnets, or nets. Once captured, the debris can be moved to a graveyard orbit or to an altitude low enough to safely re-enter the Earth's atmosphere.

Several startups, including Astroscale and ClearSpace, are strategically positioning themselves to create a market for IOS platforms that includes ADR as a service. This scheme presents spacecraft operators with an alternative approach to planning for the end-of-life phase of their spacecraft, alleviating the necessity for additional fuel to facilitate deorbiting, thereby preserving payload capacity and optimising mission planning.

Furthermore, the ESA's 2025 Space Environment Report highlights that over 54,000 objects larger than 10 cm are currently tracked in orbit, with millions more measuring in the millimetre range. Notably, the report points out that most fragmentation events result from non-collision breakups of defunct satellites and rocket bodies, precisely the targets for ADR. Even under optimistic scenarios of high compliance with mitigation measures, models like ESA's DELTA simulation indicate that debris populations will continue to grow without active removal efforts. This reality underscores why ADR is not only receiving increased attention but is becoming a crucial operational component for maintaining the long-term usability of near-Earth orbits [1].

1.3 Paper objective and approach

This effort aimed to assess where the ADR market stands today, identifying the limits and gaps, whether legislative or technological, that are preventing the ADR market from developing further. To illustrate how a suitable business model could be built, the paper presents the case study of INSIDeR, an ADR solution patented and under development at CT Ingenierie, exploring how an embedded, host-integrated ADR system could align with emerging market needs and under which conditions such a solution could become economically viable and operationally scalable. Through this example, the paper also explores how ADR could be deployed within existing mission architectures and contribute to making debris removal a routine, integrated component of future space operations.

2. Current State of ADR

ADR has emerged as a critical component of space sustainability strategies. While technological progress has been substantial, operational adoption remains elusive. This section synthesises current technical, regulatory, economic, and strategic insights to comprehensively understand today's ADR landscape.

2.1 Technical Progress

Over the past decade, ADR technologies have undergone significant development, with several key capabilities advancing from conceptual designs to actual demonstrations in orbit. Missions such as RemoveDEBRIS, ClearSpace-1, and ELSA-d have been instrumental in validating operations related to rendezvous and proximity (RPO), guidance, navigation, and control (GNC), as well as capture mechanisms [2][3][4]. These missions confirm that ADR will soon be technically feasible.

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For example, the RemoveDEBRIS mission, coordinated by the Surrey Space Centre and partly funded by the European Commission, was the first to demonstrate multiple ADR technologies in orbit. Launched in 2018 via the ISS, the mission included a series of successful demonstrations: a net capture of an inflated CubeSat acting as debris, a vision-based navigation (VBN) system using optical and LiDAR cameras, a harpoon fired at a deployed target, and a drag sail deployment for accelerated deorbiting. The net capture sequence showcased a fully in-orbit, autonomous engagement of a tumbling target using a six-mass, drawstring-based net, simulating the dynamic behaviour of a larger piece of debris. Although the drag sail deployment experienced anomalies, the mission still marked a significant milestone in validating ADR subsystems at scale [2].

The ELSA-d mission, developed by Astroscale and launched in 2021, was the first commercial mission to demonstrate technologies for satellite servicing and ADR in low Earth orbit. It involved a servicer satellite and a client satellite, simulating the removal of space debris. This mission successfully executed multiple demonstrations, including manual magnetic capture and controlled approach operations. In its first demonstration, the servicer released the client satellite and achieved magnetic docking using onboard sensors. Nevertheless, the planned autonomous capture was aborted due to anomalies. Despite losing four of its eight thrusters, the servicer demonstrated advanced RPO capabilities, reaching within 160 meters of the client satellite and operating in orbit for over two years. The mission concluded in early 2024 with a controlled deorbit to approximately 500 kilometres, ensuring reentry within 3.5 years. The client satellite is anticipated to reenter within five years, marking a noteworthy milestone for commercial satellite servicing and space sustainability [3].

ClearSpace-1 is ESA's flagship ADR mission, set to be the first to demonstrate the complete removal of a defunct object from orbit. The mission will rendezvous with, capture, and actively deorbit a spent upper-stage adapter, returning it safely to Earth's atmosphere. Procured by ESA as a service contract in 2020, the mission is being developed by a consortium led by OHB SE, with Swiss startup ClearSpace in charge of proximity and capture operations. Following funding confirmation at ESA's Ministerial Council in 2022 and a successful programme review in 2023, the mission is now in an advanced preparatory phase under ESA's Space Safety Programme. As a cornerstone of the Zero Debris Approach, ClearSpace-1 aims to validate essential ADR capabilities and serve as a symbol of Europe's leadership in embedding debris mitigation within operational practices. Its development is closely aligned with the principles and goals set out in the Zero Debris Charter, offering a precedent for future ESA missions and global industry actors to incorporate ADR into the lifecycle of space activities [4][5].

These missions are clear indicators that ADR capabilities will become available very soon, and now is the time to begin defining how these technologies can evolve beyond one-off demonstrations. Without careful architectural planning, ADR systems risk being mission-specific and optimised only for certain types of debris, orbital inclinations, or timeframes [6]. This limitation could reduce their adaptability and hinder economic scalability. Ensuring interoperability and mission flexibility will be crucial for widespread adoption and long-term market viability.

2.2 Limitations & Gaps

ADR remains stuck in the pre-operational phase despite substantial technical progress [6]. Most missions conducted so far have been custom, one-time demonstrations optimised for specific targets, environments, or orbital profiles. This narrow focus has limited the transferability of solutions and hindered the establishment of a foundation for repeatable, scalable operations.

One major limitation is the lack of standardisation of interfaces for rendezvous or capture, such as visual markers, grapple fixtures, or optical targets. This absence prevents the development of modular and interoperable ADR systems [7][8]. Even cooperative target removal is complicated and costly due to the lack of shared design norms and servicing aids. High-risk regions, such as sun-synchronous orbits at approximately 850 km altitude and inclined at 70–80°, pose significant challenges due to the high density of objects and the specific guidance, navigation, and control (GNC) complexities associated with these inclinations [1]. These orbits are also home to commercially valuable activities, such as Earth observation and telecommunications, which heighten the situation's risk and urgency [1]. However, scalable solutions tailored to address these high-risk clusters are still lacking [6].

Environmental constraints further complicate the deployment of ADR systems. The diversity of ADR concepts, ranging from inflatable braking devices (IBDs) and solar sails to plasma tethers, ground-based lasers, and ion-beam shepherding, demonstrates both the innovation of the field and its fragmentation [9]. IBDs are most effective below 800 km, while solar sails perform better at higher altitudes. Laser ablation and contactless plasma propulsion show promise but require extreme precision in relative navigation and bidirectional thrust control.

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Large systems like solar-thermal reflectors may offer scalable power. However, their size and complexity necessitate in-orbit assembly, which introduces new logistical and integration challenges [9]. In addition to these technical constraints, significant difficulties arise in navigation and control. Proximity operations, docking, and capture demand levels of autonomy that exceed current operational standards [10]. Signal delays and the complexities of orbital robotics hamper ground control. Concepts such as teleprogramming, where simulated environments are used to predefine sequences for onboard robotic execution, are still in the early stages of development. Even high TRL concepts, like expandable foam sails, must overcome debris anchoring, stability, and deployment sequencing challenges [9]. Debris volatility introduces another layer of uncertainty in space operations [1]. The ClearSpace-1 mission, originally designed to remove a specific adapter, had to change its target after the original object fragmented [11]. This incident highlights the real-world unpredictability of orbital conditions and how they can undermine even the most well-prepared plans.

Additionally, determining which debris to prioritise for removal remains a complex and unresolved challenge. Simulations conducted by ESA suggest that removing just five high-mass objects each year from high-collision-probability orbits significantly reduces the risks of cascading collisions. However, the most suitable removal method often depends on each debris object's shape, mass, rotation, orbital lifetime, and associated risk. There is currently no clear framework for comparing removal techniques across different debris categories, which complicates informed investment and policy prioritisation. Institutional programs have also faced these challenges. NASA's OSAM-1 and OSAM-2 missions, intended to demonstrate robotic servicing and refuelling, were ultimately cancelled due to cost overruns and complexity [10]. These cancellations illustrate that ADR requires technical maturity, fault tolerance, and stable funding over extended timelines.

The dual-use nature of rendezvous and proximity operations (RPO) and ADR systems presents strategic challenges. Technologies designed for debris capture, such as autonomous rendezvous and docking, have capabilities that overlap with those used in military counter-space missions. This lack of transparency regarding intent or usage can lead to mistrust, complicating international coordination and commercial adoption. The absence of trust-based verification or norms for differentiating peaceful ADR from hostile operations remains a critical gap [10].

In summary, while the standardisation of ADR is underway, these systems face structural obstacles related to design, deployment environments, and institutional reprioritisation. Until standardisation frameworks are established, autonomy technologies mature, and a global consensus is reached on mission prioritisation and transparency, ADR will remain a technically advanced but operationally limited field.

2.3 Policy & Legal Ambiguity

The ADR legal and policy landscape remains fragmented, ambiguous, and structurally weak. While international frameworks such as the UN COPUOS guidelines and ISO standards promote post-mission disposal, they are non-binding and inconsistently applied [12]. Global compliance with the 25-year rule varies significantly, often falling below 60% even in best-case scenarios. New ESA internal guidelines, such as 5-year disposal targets and strict post-mission collision probability thresholds, signal leadership but remain voluntary and unenforced.

At the heart of the legal dilemma lies the fact that orbital debris retains its original ownership. Under the Outer Space Treaty and related conventions, only the launching state has legal authority over a space object, even if it is defunct or fragmented, making debris removal by third parties legally impossible without explicit consent. This obstacle is especially acute when the object is abandoned, unresponsive, or unattributable. This legal constraint, combined with potential liability exposure, creates a chilling effect on ADR operations [13].

The European Space Policy Institute adds that while international instruments increasingly converge on core principles, they lack implementation pathways and enforcement tools. It warns that voluntary instruments cannot ensure compliance without stronger monitoring and institutional authority [12]. The report calls for Europe to lead multilateral initiatives, such as the Zero Debris Charter, to consolidate regulatory and operational norms. The absence of binding multilateral agreements specific to debris remediation also hampers international coordination. Most progress happens through national initiatives or bilateral demonstration missions, which do not scale into global norms.

Meanwhile, commercial actors have begun to fill the policy vacuum. Companies like Astroscale have played a leading role in advocating for the development of global standards, contributing to UN COPUOS, the Inter-Agency Space Debris Coordination Committee (IADC), CONFERS, and the World Economic Forum's Space Sustainability Rating initiative. These efforts show that private operators are actively shaping guidelines, best practices, and technical norms that could become de facto standards in the absence of binding agreements [14].

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Regional regulatory responses to this legal gap are varied. There have been isolated efforts to integrate end-of-life disposal into licensing regimes and spaceflight safety regulations in Japan, the United States, the UK, and within ESA member states. However, these national frameworks are not harmonised internationally, and cross-jurisdictional coordination remains a challenge, especially for missions targeting debris owned by multiple or unknown actors.

The 2021 proposal by Way & Koller introduces a pragmatic legal pathway to enable ADR within the current treaty framework. Their model suggests that ADR missions can proceed under a consent-based framework grounded in regulatory oversight, inter-agency Memoranda of Understanding (MOUs), and contractual clarity without needing ownership transfer. This approach enables scalable debris removal between like-minded actors and provides a legal model for operational missions today [13].

Still, unresolved issues remain. Export control laws such as ITAR complicate technology sharing in international ADR collaborations. Licensing complexity, liability attribution, and the dual-use nature of ADR technologies, especially those enabling autonomous rendezvous and manipulation, raise concerns over transparency and potential military applications. Trust-building through transparency, intent declaration, and open communication is essential for avoiding geopolitical friction and maintaining confidence in peaceful uses of space [13].

In summary, while legal ambiguity remains one of the most cited barriers to ADR, the current moment offers an opening for transition. Voluntary guidelines, regional licensing systems, and new norms from the private sector are establishing a framework for future policy coherence. For ADR to become more widely accepted, we must shift legal clarity from being a permissive exception to an operational norm. This process is already taking place through practical legal design rather than sweeping treaty reforms.

2.4 Economic & Incentive-Related Barriers

Despite growing technical maturity, ADR remains commercially stagnant due to unresolved economic and incentive-related gaps. There is currently no established market for ADR, no clear recurring customer base, and limited insurance incentives for debris mitigation or removal. As a result, most ADR efforts remain in pilot or demonstration phases. This outcome reflects a classic case of market failure [15]. Orbital debris presents a negative externality: It imposes widespread costs on all operators, yet no single entity has enough incentive to cover risk mitigation costs. Launchers and satellite operators can exploit shared orbital space without bearing the full long-term consequences. This situation represents a classic example of a public good being degraded due to a lack of coordinated regulation and inadequate early intervention [16].

Simulations conducted by ESA and NASA have demonstrated that the targeted removal of just five high-mass, high-risk objects per year can significantly reduce the long-term risk of cascading collisions in space and help maintain the viability of congested orbital bands. However, operators rarely undertake such initiatives without direct financial incentives or clear regulatory mandates. ADR is typically viewed as an optional investment rather than a necessary operating expense, often lacking immediate returns [15].

This situation has profound economic implications. Research has shown that the financial effects of inaction termed the "economic Kessler Syndrome," can manifest long before a physical cascade of collisions occurs [17]. As the risk environment deteriorates, launching new satellites becomes economically unviable due to increased insurance costs, the risk to service continuity, and diminished returns on investment. Without policy changes, orbital space may become underused or inaccessible, not because it is full, but because operating there is unprofitable.

Regulators and agencies are starting to take action. For instance, ESA's Zero Debris Charter calls for shared responsibility among operators, manufacturers, insurers, and regulators. Its procurement model for ClearSpace-1, which treats debris removal as a contracted service, establishes an important precedent. However, these efforts remain isolated and exploratory. Broader public-private partnerships (PPPs) could help create early demand and reduce the risks of commercial investment, especially with the involvement of government-backed anchor customers [15].

The problem is compounded by the absence of standardised pricing models for ADR. According to NASA's 2023 report from the Office of Technology, Policy, and Strategy (OTPS), cost benchmarks for various ADR architectures range from $6,000 to $18,000 per kilogram of debris removed, depending on the mission profile and propulsion configuration. However, there are currently no established pricing frameworks for ADR services that consider factors such as the type of object, its mass, the reduction in collision probability, or compliance with licensing. This lack of standardised pricing limits economic predictability for service providers and customers [18].

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Several proposals aim to connect ADR to insurance frameworks, such as providing reduced premiums for operators who engage in sustainable practices or creating risk-weighted contributions to a debris mitigation fund, similar to maritime or environmental insurance practices. However, insurers have yet to implement these models at scale, primarily due to regulatory inertia and the absence of quantifiable baselines for risk reduction [15].

To facilitate more thoughtful prioritisation, the ESA's Clean Space initiative has introduced the "Steve Index." This index estimates the economic value of removing specific debris objects by considering factors like mass, orbital lifetime, collision risk, and the monetary value of nearby assets [19]. This approach shifts ADR planning from focusing solely on technical optimisation to value-based decision-making, enabling arguments for debris removal based on potential net economic benefits.

Recent studies on economic architecture confirm that effective ADR services rely heavily on the context of the orbit and the mission architecture. One study found that using Electric Propulsion combined with Electrodynamic Tether systems, deployed via a mothership design, proves to be cost-effective for removing clustered high-mass debris. However, cleaning orbits such as Sun-Synchronous Orbits (SSO) at approximately 850 km altitude remains prohibitively expensive without breakthroughs in operational costs or improvements in multi-target efficiency [20].

Even with optimised architectures, ADR only becomes cost-effective when considered a long-term infrastructure investment. NASA presented a framework in which the benefits of ADR, such as reduced collision risk, protection of orbital capacity, and preservation of satellite functionality, accumulate significantly over multi-decade timeframes rather than providing immediate cost savings. Their model indicates that the net present value (NPV) of debris removal is highest when it accounts for systemic risk reduction over a 30 to 50-year period. This long investment horizon discourages purely commercial actors and highlights the necessity for early-stage public procurement, demand aggregation, and policy-backed incentives [18].

Moreover, while soft incentives like the Space Sustainability Rating (SSR) and procurement scoring for sustainable practices are emerging, their economic impact remains limited. Operators may gain reputational benefits or slight procurement advantages, but this often does not alter market behaviour without stronger financial or regulatory connections [21].

In summary, ADR is hindered by the absence of a viable economic framework. ADR will remain technically feasible but economically unsupported without effective pricing models, aligned insurance incentives, demand aggregation, and long-term risk ownership. Establishing this market will necessitate coordinated efforts from regulators, agencies, and insurers to develop the incentives and financial instruments to make orbital remediation essential and investable.

2.5 Synthesis: ADR is technically plausible but structurally unsupported

While technical feasibility has advanced, structural, legal, and economic enablers remain missing, preventing any operational ecosystem from emerging. A significant imbalance characterises the current landscape of ADR: while technical feasibility is improving, the accompanying legal, economic, and regulatory frameworks are inadequate for effective operational deployment. Demonstration missions such as RemoveDEBRIS, ELSA-d, and ClearSpace-1 have successfully shown that ADR can be performed safely and with increasing levels of autonomy. Key technologies, including capture mechanisms, guidance and navigation systems, and end-of-life deorbit tools, are rapidly maturing. However, these technologies remain confined to specific missions and have not developed into repeatable services or broader industrial capabilities.

At the same time, the lack of regulatory alignment, standardised licensing mechanisms, and clear liability guidelines continue to hinder commercial actors from implementing ADR solutions without navigating complex legal landscapes. The absence of binding multilateral agreements on debris removal, coupled with unresolved issues regarding object ownership and the sensitivities around dual-use technology, perpetuates legal uncertainty and deters investment. Even where national or regional initiatives exist, they are fragmented and do not yet create a cohesive global framework.

Economically, ADR is trapped in a pre-market state. Studies from organisations like ESA, NASA OTPS, and the OECD indicate that targeted, high-priority debris removal could offer long-term systemic benefits. However, the lack of price signals, insurance incentives, and dependable customers has obstructed the formation of a meaningful market. In this context, technical readiness alone cannot drive deployment. Public funding remains the primary enabler, yet this support is concentrated in isolated initiatives such as ClearSpace-1 or specific national research programs.

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Additionally, the sector struggles with issues related to interoperability and mission-specific design. Many current ADR systems are optimised for particular orbital inclinations, debris types, or servicing timelines, which limits their adaptability and economic viability. Without a concerted effort toward standardising interfaces, prioritisation models, and operational design rules, the ADR sector risks repeating the mistakes of earlier satellite servicing initiatives, where one-time missions failed to evolve into viable services.

In summary, ADR today represents a capability that lacks a supportive ecosystem. Technologically, the field is nearing readiness, and strategically, demand is increasing. However, operationally and economically, ADR lacks the necessary enabling environment to scale. Unless these structural gaps, such as legal clarity, economic incentives, policy coordination, and international collaboration, are addressed, ADR risks remaining a niche capability implemented symbolically rather than systematically.

3. INSIDeR System: A Case Study in Embedded ADR

This section presents the INSIDeR system as a case study, highlighting its architecture, subsystem design, and potential applications. By illustrating how debris capture capabilities can be modularised and integrated into existing platforms, INSIDeR helps demonstrate what practical, scalable ADR might look like under the right market and policy conditions.

3.1 Concept Summary

INSIDeR, which stands for ***I**nnovative **N**et & **S**pace **I**nflatable Structure for Active Debris Removal*, is an ADR solution patented and under development at CT Ingenierie. As a modular, host-integrated kit, INSIDeR enables spacecraft to capture and remove debris as part of the mission disposal procedures. Its architecture is built around two main segments:

- **A net capture mechanism** engineered to secure objects of various shapes, sizes, and tumbling rates.
- **An inflatable structure** that allows for the deployment and stabilisation of the net near the target, improving precision and reducing the kinetic risk associated with projectile-based net concepts.

INSIDeR functions as an external secondary payload, minimising the added complexity to the design and operations of the host vehicle. In addition, the overall system is low-cost due to its reliance on commercial off-the-shelf (COTS) components and its modularity across platforms.

The solution leverages the host platform's existing propulsion and guidance, navigation, and control (GNC) systems, enabling ADR as a complementary capability and secondary mission objective. At the conclusion of the host's intended mission, INSIDeR is activated, allowing the host to capture a nearby piece of debris and deorbit it alongside the host during atmospheric reentry. INSIDeR's operational concept includes four main phases:

- **Characterisation Phase**: Once activated, the system begins with a long-range characterisation of the selected debris target. Optical sensors and telemetry data localise the object and assess its orbital parameters, rotation state, and geometry.
- **Approach Phase**: With support from ground control, the host platform receives updated GNC data and performs a sequence of approach manoeuvres. These are modelled after the ATV rendezvous procedures and include multiple hold points with "go/no-go" decision gates to ensure operational safety.
- **Capture Phase**: When the host reaches a final station-keeping position approximately 100 meters from the target, the inflatable structure deploys, extending and orienting the capture net. A final approach manoeuvre pushes the net forward to ensnare the debris. At this point, a mechanical locking system secures the net around the target.
- **Deorbit Phase**: Once capture is confirmed, the host initiates a controlled deorbit burn. A tether transmits the deorbit loads from the host to the debris, ensuring both objects reenter Earth's atmosphere.

INSIDeR's design philosophy emphasises affordability, scalability, and operational simplicity. It aims to integrate debris remediation into routine operational activities by embedding capture-and-disposal as part of the end-of-life procedures of future space missions.

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3.2 Subsystem Architecture

The figure below shows the logical decomposition of INSIDeR into seven subsystems. The logical components of the INSIDeR kit are highlighted in dark blue, while the grey notes in the background represent the intended physical implementation of these components.

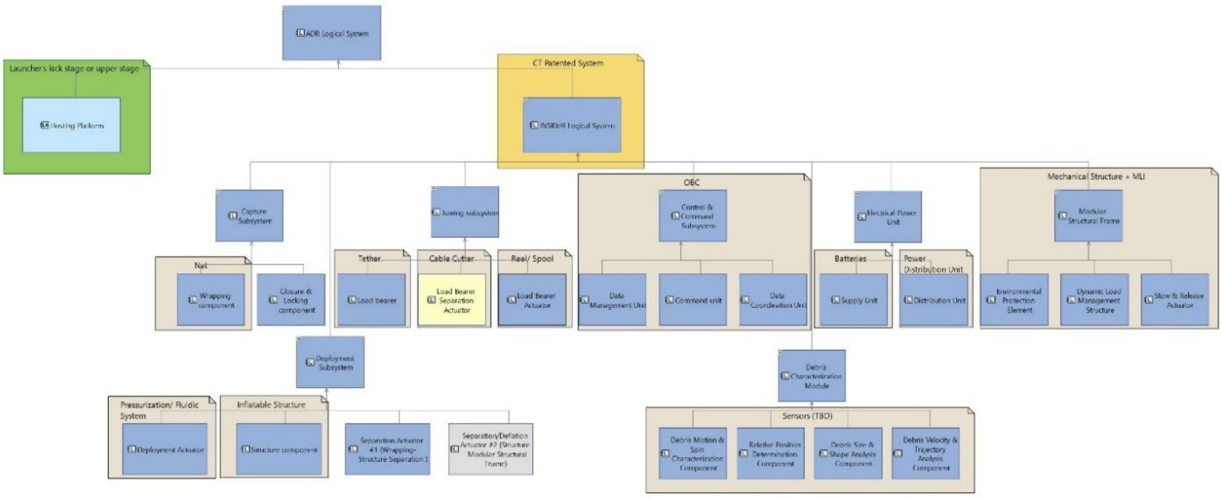

Figure 1: Logical Decomposition of the INSIDeR Kit

3.2.1 Capture Subsystem

The primary function of this system is to capture and contain targeted debris. It consists of two components: a wrapping component, which is a net, and a closure and locking system designed to secure the captured debris. The net's size and mesh are scaled according to the size of the debris, allowing it to target a wide range of objects. The net's envisioned shape is circular, enabling it to accommodate various debris shapes. The mesh size is designed to ensure that no part of the debris can escape.

The net’s material is Dyneema, known for its high strength and flexibility, and it has been proven effective for use in space. The locking system features several drawstrings running around the perimeter of the net. One end of each drawstring is attached to the centre of the net, while the other is connected to a floating mass. When debris impacts the centre of the net, inertia causes these masses to move, which pulls on the drawstring and facilitates the closure of the net. Additionally, anti-return mechanisms are installed along the path of the drawstrings to prevent them from sliding back in the opposite direction, thereby ensuring that the net remains securely closed.

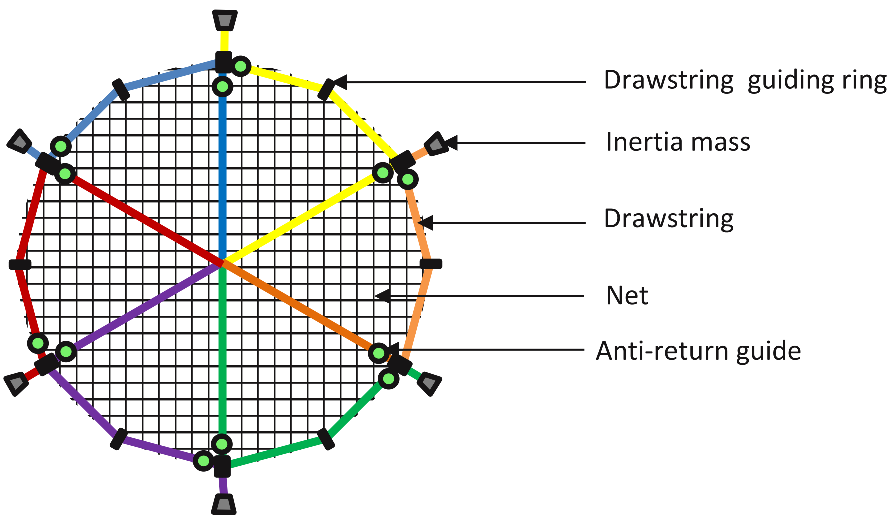

Figure 2: Capture System Illustration.

DOI: 10.13009/EUCASS2025-607

3.2.2 Deployment Subsystem

The primary function of this system is to deploy the net and set it up correctly for debris capture. It comprises four components: an inflatable structure, a commercially off-the-shelf (COTS) pressurisation system, and two separation actuators. One actuator is needed to decouple the net from the rigid inflatable structure to facilitate the closure of the net. At the same time, the other prevents the rigid structure from transferring unwanted dynamic loads to the Hosting Platform after the capture.

The inflatable structure has undergone several redesigns to improve deployment and enhance air mass flow circulation. It comprises two masts that interface with the pressurisation system and a circular structure that connects the masts, fitting the circular shape of the net to enable deployment. This structure will be manufactured as a single piece of polyethene and sealed using specialised welding techniques.

Figure 3: Inflatable Structure Prototype.

The COTS pressurisation system, which includes valves, an electronic control system, and tanks, will be supplied by an aerospace fluidic system provider. The proposed separation systems for disconnecting the net from the inflatable structure are designed as mechanical fuses that will break and release the net upon the impact of debris entering it. Additionally, the suggested mechanism for deflation or separation of the inflatable structure from the hosting platform involves thermal wires that will melt the structure at its base.

3.2.3 Towing Subsystem

The primary function of this system is to transfer loads between the Debris and the Hosting Platform, enabling the towing of the Debris until its deorbit. This subsystem consists of three components, one of which is optional (highlighted in yellow) depending on the mission configuration. The two primary components of the Towing Subsystem are a cable, commonly referred to as a tether, and a reel or spool for managing the deployment of the tether. The optional component is an actuator that facilitates the separation between the {Tether + Capture Subsystem + Debris} on one side and the {INSIDeR Mechanical Frame & Hosting Platform} on the other. This actuator is particularly useful for specific use cases, which will be discussed later. The tether is envisioned to be made from Zylon, as it offers beneficial thermal and traction resistance properties.

3.2.4 Modular Structural Frame

The primary function of this frame is to maintain the integrity of the INSIDeR kit. In practice, this frame serves as the mechanical structure that encloses all the INSIDeR components during flight. Multi-layer insulation (MLI) will be added to ensure thermal regulation and protection. Additionally, a Stow & Release Actuator will be incorporated to facilitate the release of the inflatable structure and net.

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3.2.5 Control and Command Subsystem

The Command & Control Unit serves as the central avionics' controller, coordinating the actuators, processing data from onboard sensors, and managing communications with both the Hosting Platform and the Ground Segment. It interfaces with the Hosting Platform to exchange mission initiation commands, monitor and coordinate propellant usage for manoeuvres, and manage power and thermal data as applicable. For specific mission phases or contingencies, the Command & Control Unit is responsible for autonomously aborting the mission without ground intervention.

3.2.6 Electrical Power Unit

The primary function of this system is to distribute electrical power to all of INSIDeR's required subcomponents. It consists of two components: a Distribution Unit and a Supply Unit. The Supply Unit is intended to be a set of batteries. However, optionally, the Hosting Platform could provide the required power to INSIDeR. In that scenario, a power interface would be added.

3.2.7 Debris Characterisation Module

The primary function of this system is to perform a close-range characterisation of debris to verify its condition before deploying the net. It consists of four logical sensor components: the Debris Motion and Spin Characterization Component, the Relative Position Determination Component, the Debris Size and Shape Analysis Component, and the Debris Velocity and Trajectory Analysis Component. The physical architecture of these components is still to be defined in collaboration with specialised industrial partners.

As can be anticipated from the architecture description of INSIDeR, the architecture itself can be modular and slightly adapted based on the mission configuration and the capabilities of the hosting platform. This specific aspect is further explained in the next section.

3.3 Deployment Logic

As mentioned earlier, INSIDeR and the hosting platform form the ADR system together. While the INSIDeR kit handles the capture function, the hosting platform performs other critical functions essential to the ADR mission, such as propulsion, attitude control, guidance, navigation and control (GNC), and telecommunications.

The architecture of INSIDeR may be simplified depending on the capabilities of the hosting platform. If the platform provides available power levels and interfaces compatible with the kit, INSIDeR will not need to include its onboard power source. Similarly, if the hosting platform's sensors allow it, the platform can conduct close-range characterisation directly. Therefore, power supply and characterisation are functions that can performed by either the INSIDeR kit or the hosting platform.

However, the hosting platform must carry out several functions. These include GNC for reaching the debris orbit, propulsion for various manoeuvres (such as approach and deorbitation), attitude control to ensure proper orientation of the capture system relative to the targeted debris, and telecommunications with the ground station. Though redundancy may be used to secure operations within the INSIDeR kit, these functions are standard for any spacecraft capable of manoeuvring in space. This compatibility ensures that the INSIDeR kit can be deployed on various platforms. However, some interfaces or internal architecture adjustments may be necessary depending on specific use cases, which will be detailed below.

3.4 Representative Use Cases

Three representative use cases are defined for ADR missions using the INSIDeR kit. Each use case corresponds to a different type of hosting platform, which may be a launch vehicle upper stage, a satellite within a constellation, or an IOS Platform.

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3.4.1 Launch Vehicle Upper Stages

Access to space is a fundamental service for any space application, and the number of launchers being developed and launched is continually increasing. With the evolution of space law and growing awareness of the need for debris mitigation, modern upper stages need to plan their reentry after delivering customer satellites to their intended orbits. Utilising INSIDeR as a secondary payload on these upper stages could help control the number of orbiting objects by removing one debris piece for each launch that adds new satellites to space traffic. The captured debris will be destroyed during the reentry of the upper stage. The operational sequence for launch, from take-off to the release of customer satellites into their working orbits, is relatively short. Therefore, it is feasible for this specific use case to employ a version of the INSIDeR kit that includes its own batteries. This configuration can simplify the interfacing tasks required to integrate INSIDeR with various launch vehicle upper stages, although other interfaces, such as communications and mechanical connections, will still need attention.

3.4.2 Satellite Constellations

Constellation operators could equip a fraction of satellites with INSIDeR kits for internal redundancy and post-mission deorbiting, acting as pre-positioned ADR assets. These satellites could be repurposed at the end of their nominal life to service high-risk debris or failed satellites, either within the same constellation or external to it. This dual-purpose role introduces the possibility of constellations contributing to the broader orbital remediation market, offering ADR services as a secondary revenue stream. Since these assets are already in orbit, their operational cost for a final ADR mission is lower than deploying a dedicated ADR platform. They also benefit from known positioning, control infrastructure, and available power and propulsion systems, key enablers for safe proximity operations. While theoretical, this vision aligns with emerging concepts of multi-role satellite design and space infrastructure sharing, helping to amortise costs and distribute sustainability responsibility across commercial operators.

3.4.3 In-Orbit Servicing Platforms

INSIDeR could also be deployed on IOS Platforms, where it could operate as a standard module alongside repair and refuelling functions. One or more kits could be attached to a single IOS Platform, transforming it into a space debris collector. The debris would be removed one piece at a time: the IOS Platform would capture the first piece of debris, lower its altitude until reentry, and then use a cable cutter to separate it from the debris, allowing the debris to reenter the atmosphere while the platform remains in orbit. An actuator would be needed to operate the tether cutter in this scenario. Additionally, since IOS Platforms stay in orbit for extended periods, it would be preferable for the kit to draw power from the hosting platform, as embedded batteries may deplete over time.

3.5 Framing INSIDeR's Impact

INSIDeR is a concrete example of what effective ADR could look like, assuming the proper market conditions, policy frameworks, and operational incentives are in place. Instead of treating debris removal as a distinct mission requiring dedicated infrastructure, INSIDeR redefines ADR as a service integrated directly into the lifecycle of existing space assets. As a modular deorbitation kit, INSIDeR can be hosted on various platforms, enabling them to perform an additional debris removal operation at the end of their mission. This approach transforms ADR from a one-time event into a routine capability incorporated into the planning and design of space missions. To support this level of integration, the INSIDeR kit would have multiple configurations that optimise mass, power consumption, and interface complexity based on the hosting platform. These variations ensure minimal disruption to the primary mission while maintaining adequate performance for debris characterisation, capture, and deorbitation.

Standardising interfaces would enable INSIDeR to scale across different platforms, reducing the barriers to adoption and simplifying mission planning through common mechanical, power, and data connections. Such a feature is essential for platform providers to integrate ADR without compromising payload capacity or platform flexibility. INSIDeR variants could also be tailored to target different classes of orbital debris, from defunct small satellites to larger, mission-critical targets like upper stages, depending on the capabilities of the host platform. While not all debris can be addressed by all platforms, the system's architecture would allow for targeted deployment strategies that maximise return on investment and mission compatibility. If widely adopted, systems like INSIDeR could significantly change the economics of ADR, replacing specialised removal missions with distributed infrastructure integrated into routine missions. In doing so, INSIDeR could provide a clear and viable pathway to achieving operational sustainability in orbit at scale.

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4. Enabling a Scalable ADR Ecosystem

The future implementation of ADR will not be determined by technology alone. Legal, economic, and operational frameworks must evolve to support scalable, routine debris mitigation. This section proposes a path forward by identifying and discussing the key enablers that will facilitate the transition of ADR from exception to norm.

4.1 Policy and Legal Enablers

The current legal regime governing orbital activities is one of ADR's most persistent blocking points. Existing international space law, particularly the Outer Space Treaty (OST) and Liability Convention, still anchors ownership and jurisdiction over space objects to the launching state, even when the object is defunct, fragmented, or threatening. This foundational principle blocks third-party remediation unless the state of registry grants explicit consent. As a result, ADR missions operate under a consent-based legal model, often negotiated on a case-by-case basis through inter-agency memoranda of understanding or national licensing procedures.

One study called attention to the inadequacy of this framework for managing an increasingly congested orbital environment. There is still no binding international definition of "space debris" nor any legal threshold that distinguishes an object as abandoned, hazardous, or no longer subject to sovereign rights [22]. This gap introduces uncertainty in operational planning, liability attribution, and insurance underwriting. Proposals have emerged to introduce formal definitions that integrate criteria such as non-functionality, lack of control, and failure to register or maintain jurisdiction. In parallel, comparative legal frameworks, such as maritime salvage law, offer instances that could justify remediation in cases of threat or abandonment, even absent a clear claim of ownership.

The absence of criteria for relinquishing ownership or jurisdiction is a core blocker to ADR. Without legal recognition of abandonment or an object's transformation into no longer under effective jurisdiction, even non-functional satellites remain protected from removal. This problem has prompted calls for legal development of trigger conditions, such as loss of control or tracking failure, that could justify or even authorize third-party remediation under defined rules. In a practical innovation, the Debris Offset Market (DOM) concept introduces the notion of "Debris Tickets": formal declarations by the owner or launching state that specific objects are open to remediation under predefined legal terms [23]. These tickets provide a lightweight but legally valid method for enabling consent while reducing liability exposure. Furthermore, recent work suggests consent could be proactively embedded into national licensing procedures via pre-consent clauses for future ADR eligibility. Such a shift would not undermine sovereignty but instead create a clear, conditional legal pathway for operators and removal service providers to act when predefined criteria are met.

The lack of enforcement mechanisms compounds the problem. While UN COPUOS guidelines and ISO standards promote post-mission disposal and orbital responsibility, their voluntary nature limits their impact [24]. Nevertheless, recent developments in space governance show a growing willingness among emerging space nations to engage proactively with sustainability norms. Nations such as Nigeria, Rwanda, Azerbaijan, and Thailand have become signatories to soft-law initiatives like the Artemis Accords and the Net Zero Space Declaration. These actions demonstrate the demand for space sustainability governance and the formation of globally recognized legal norms that reflect this expanding diversity of stakeholders [22].

The Space Sustainability Rating (SSR) framework also presents a novel enabler for legal harmonization. Developed by an international consortium and now managed by a dedicated non-profit, the SSR translates abstract policy goals into measurable operational behaviours. For regulators, the SSR can support national licensing procedures by offering quantitative and qualitative benchmarks for sustainability. In addition, the SSR provides a practical reference model for embedding sustainability into national legislation for emerging nations while reducing dependency on opaque or high-barrier global enforcement mechanisms [12].

The way forward is to transition from non-binding recommendations to enforceable operational obligations. Licensing frameworks could integrate debris removal mandates as part of flight safety conditions. National and regional regulatory authorities could require consent-based ADR provisions in licensing terms, especially for legacy objects. Similarly, data-sharing obligations under Space Traffic Management (STM) regimes could provide the transparency and predictability needed to enable cooperative debris removal across jurisdictions [24]. Ultimately, ADR must evolve from being merely legally permissible to being legally expected. This approach means developing policy instruments that encourage or require operators to plan for third-party disposal as part of mission closure. In doing so, the legal system would shift from treating ADR as an exceptional intervention to framing it as a standard part of lifecycle planning.

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4.2 Economic and Insurance Incentives

ADR is currently suffering from a classic market failure. While all orbital users benefit from cleaner orbits, no individual actor has sufficient incentive to pay for the cleanup. As a result, IT remains technically feasible but economically unattractive. Without an anchor customer base, standardised pricing models, or demonstrable return on investment, commercial actors will remain hesitant to engage [15].

The absence of meaningful insurance mechanisms reinforces this conduct. Most satellite insurance policies do not reflect the differentiated risk of operating in congested orbits or reward operators for participating in ADR. However, proposals are emerging to address this gap. One concept involves premium reductions for missions that engage in debris remediation or risk-based contributions to a global orbital sustainability fund. These ideas mirror mechanisms used in the maritime and environmental insurance sectors. The legal uncertainty further complicates the picture as insurers face a lack of clear liability boundaries and risk ownership transfer ambiguity when evaluating ADR scenarios [22]. Without clarity on who is liable during and after debris removal, insurers are unlikely to cover such missions, keeping premiums high and participation low. Standardised liability-sharing agreements and regulatory templates could reduce risk exposure and promote market participation in this context.

The DOM model offers a more structured solution, which proposes a non-tradable, risk-adjusted offset contribution from all operators based on the debris risk posed by their missions. These funds are pooled into a public trust or dedicated ADR fund to finance remediation missions at scale. Contributions would be calculated based on object mass, orbital characteristics, mission duration, and sustainability score, ensuring the system reflects a "polluter-pays" logic. According to the proposal, even a 1% contribution from each satellite's lifecycle cost could enable 5–10 ADR missions annually, a meaningful starting point. DOM could fit naturally into insurance policies or launch contracts, allowing offset contributions to be a line item during mission budgeting. This action lowers transaction friction and provides a familiar pathway for industry adoption without requiring immediate legal reform [23].

Another challenge is cost predictability. Estimates from ESA and NASA suggest that ADR missions may range from $6,000 to $18,000 per kilogram of debris removed, depending on mission architecture. Yet, no standard pricing schema allows customers to assess cost-benefit trade-offs based on object mass, orbital lifetime, or proximity to critical assets. ESA's Clean Space initiative introduced the Steve Index to evaluate the economic value of removing specific debris objects, but this tool remains limited in its application.

The Space Sustainability Rating (SSR) adds a valuable economic layer in this context. Its tiered scoring system (Bronze to Platinum) benchmarks sustainability practices and serves as a soft incentive, in other words, a public signal of responsible behaviour. One study confirms that emerging space nations can achieve SSR scores on par with or higher than established actors, undermining the perception that sustainability expectations pose a barrier to entry. Instead, it highlights that sustainability can be a competitive asset in attracting funding and reducing regulatory friction [22].

Addressing these gaps will require a layered approach. Public sector actors must act as early anchor customers at the highest level, commissioning ADR services to build operational maturity and drive down costs. Public-private partnerships can de-risk early-stage investment, particularly if national procurement frameworks explicitly value orbital sustainability. In parallel, insurance providers and licensing bodies could work together to embed debris removal as a factor in risk assessment and operational compliance. The DOM framework represents a credible tool to internalise ADR costs transparently and align economic incentives with long-term sustainability. Ultimately, the viability of ADR will hinge on its economic normalisation. The transition will occur not when debris removal becomes profitable on its own but when it is treated as a shared infrastructure investment that enables sustainable access for all and is costed into the broader economics of mission planning.

4.3 Standardization and Interoperability

Despite progress in demonstration missions, the lack of standardised ADR interfaces limits operational scalability. Existing ADR systems are often tailored to specific targets, orbital regimes, and servicing platforms, making them unsuitable for widespread deployment. This design fragmentation undermines delivering ADR as a repeatable service across platforms and mission types. The absence of shared grapple fixtures, rendezvous protocols, and characterisation data formats impedes cooperative and uncooperative servicing. Optical markers and attitude stabilisation features, which could facilitate capture and manipulation, are rarely integrated into satellite designs. Initiatives such as CONFERS, ESA CleanSpace, and ClearSpace-1 have highlighted these limitations, advocating for adopting standardised servicing architectures and data exchange formats.

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A viable ADR ecosystem will require the equivalent of "plug-and-play" compatibility between debris objects, removal systems, and host platforms. As satellite buses and payloads evolved toward modularity and interface standards, ADR components must follow suit. Solutions like INSIDeR demonstrate how modular kits can be embedded into diverse host platforms. However, such compatibility must be designed into both ends of the system: the remover and the target.

The Space Sustainability Rating (SSR) reinforces this trend by translating sustainability into a set of measurable modules, including Data Sharing, Collision Avoidance (COLA), Detectability/Identifiability/Trackability (DIT), and adoption of design standards. These modules reward designs and behaviours that implicitly support interoperability. The SSR also incorporates verification levels, giving additional weight to missions that provide evidence-based compliance, effectively nudging the ecosystem toward transparent, certifiable practices [22].

On the other hand, despite their widespread use, technical standards like ISO 24113 still lack legal status. Elevating these norms into recognised benchmarks within national law or procurement contracts would solidify their influence, particularly as ESA works toward developing mission-level KPIs for debris prevention, which could also extend to ADR equipment and service providers [24].

The Debris Offset Market (DOM) concept reinforces these dynamics by financially incentivising interoperable designs. Because DOM contributions are scaled based on object risk and sustainability practices, operators are encouraged to integrate servicing aids, improve PMD reliability, and register their objects with precise orbital metadata. While DOM does not directly define technical standards, its indirect effect is to monetise compliance with best practices, thus accelerating convergence across the design ecosystem [23].

Standardisation will also be essential for certification and procurement. ADR providers face increased costs and regulatory uncertainty without standard performance benchmarks or qualification pathways. Creating a certification regime would enhance transparency and enable public institutions to procure ADR services competitively and reliably. Moreover, interoperability must extend to data-sharing and tasking interfaces. STM frameworks must accommodate the real-time exchange of tracking data, intent declarations, and object characterisations across international lines. A system-of-systems approach will be needed in which ADR capabilities are embedded across fleets, platforms, and mission timelines.

4.4 Multi-Stakeholder ADR Market

No single actor can create an ADR market in isolation. A functional debris removal ecosystem will require the coordinated participation of public institutions, private operators, insurers, platform providers, and regulators. Each must assume complementary roles in shaping a service landscape that rewards remediation and discourages negligence.

Space agencies are in a unique position to lead by example. ESA's procurement of ClearSpace-1 as a service contract established a new precedent: debris removal can be treated not as a one-off demonstration but as an operational activity with mission-like performance requirements. Similar service-based approaches could be extended through national space programs, incentivising commercial actors to scale capacity and diversify architecture [4].

Platform providers, especially launch vehicle operators and satellite bus manufacturers, also play a central role. By embedding ADR kits such as INSIDeR into their platforms, they can transform mission end-of-life into an opportunity for orbital remediation. Meanwhile, constellation owners can treat intra-fleet redundancy as a dual-purpose capability for satellite replacement and debris capture. This distributed, embedded approach reduces cost and risk while increasing access to ADR capability.

Insurers and licensing authorities must likewise align their incentives. Whether through differentiated premiums, risk-based levies, or sustainable procurement scoring, these actors can send the market signals needed to steer industry behaviour. Finally, financial institutions, from development banks to VC firms, can support early-stage ADR ventures, particularly those aligned with ESG principles [24].

The Space Sustainability Rating (SSR) adds value as a community-building and alignment tool. Enabling membership from both operators and regulators encourages multi-stakeholder collaboration and provides a structured forum for co-developing best practices. For emerging nations, the SSR offers a benchmarking tool and a pathway to influence governance norms, as several of them are now contributing to global sustainability initiatives via COPUOS, Net Zero Space, and SSR working groups.

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The Debris Offset Market (DOM) builds upon this multi-stakeholder momentum by proposing a transparent and equitable governance structure. It envisions an independent Market Operator (MO), potentially backed by the UN or a consortium of space agencies, tasked with administering offset contributions, selecting debris targets, and reporting progress. Contributors to the DOM fund receive proportional voting rights over which debris objects are prioritised for removal, drawn from a Debris Removal Register (DRR). This system ensures accountability and shields the process from capture by dominant actors [23].

Only contributors may nominate debris targets to prevent free-riding, and only objects flagged as "open to remediation" via Debris Tickets may be considered. This dual mechanism incentivises voluntary participation and fosters a sense of shared stewardship, which is particularly important as more operators from emerging economies enter the market.

At the same time, public law must be complemented by private legal mechanisms, such as pre-consent clauses, standard contracts, and industry-wide service agreements. In the long term, this legal architecture could evolve into a "soft treaty" or multilateral framework, codifying norms, liability rules, and funding tools without requiring extensive treaty renegotiation. Such an approach mirrors successful environmental regimes in other domains [24].

Lastly, the burden-sharing dimension is essential. Like climate change, a few early actors disproportionately created the orbital debris problem, but its consequences are global. A scalable ADR market must reflect this by designing inclusive frameworks where emerging space nations are not just rule-takers but co-authors of the solution space, treating ADR as a shared public responsibility that is acceptable, accessible, and expected.

5. Conclusion

Our capability to manage an increasingly congested orbital environment will define the future of space operations. While mitigation measures help limit the growth of new debris, they fall short of addressing the legacy population that threatens orbital safety. ADR has emerged as a necessary complement to traditional debris mitigation strategies, no longer a speculative idea but a technically feasible reality. Demonstration missions such as RemoveDEBRIS, ELSA-d, and ClearSpace-1 confirm that rendezvous, capture, and controlled deorbit are within reach. Yet, despite this progress, legal ambiguity, economic uncertainty, and systemic fragmentation maintain ADR activities in the development stages.

To illustrate a path forward, we introduced INSIDeR, a host-integrated debris removal kit designed to make ADR a standard part of mission planning rather than a costly afterthought. As a modular solution deployable across diverse platforms, from upper stages to constellation satellites and servicing vehicles, INSIDeR shows how ADR can be integrated into the lifecycle of future missions. It transforms removal from a stand-alone service into a distributed infrastructure that scales with the expansion of the space economy.

This work also explored the conditions under which solutions like INSIDeR could thrive. While progress is underway, for ADR to reach operational maturity, key enablers must align:

- Policy and legal clarity to enable consent-based remediation and reduce liability friction.
- Economic instruments such as the Debris Offset Market (DOM) to internalise costs and incentivise early adoption.
- Standardisation of interfaces and certification schemes to enable interoperability across missions and platforms.
- Multi-stakeholder alignment across agencies, insurers, operators, and investors to ensure coordinated, scalable implementation.

Ultimately, the challenge of ADR is no longer about proving what can be done, but about ensuring it gets done routinely, reliably, and responsibly. The transition from exception to norm will only occur through coordinated action across regulatory, economic, and operational domains. Solutions like INSIDeR offer a tangible step in that direction: adaptable, affordable, and aligned with tomorrow's space sector. They represent not just a technical asset but a catalyst for changing how we think about sustainability in orbit.

In conclusion, the enabling conditions must now catch up with the technology. With the right incentives, frameworks, and standards, ADR can evolve from a promising capability into a global commitment.

DOI: 10.13009/EUCASS2025-607

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