Airbus Active Debris Removal Projects

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ABSTRACT

With the decrease in cost for launching into space, and growing customer demand, there has been an increasing number of smallsat constellations being brought to market, each with up to thousands of individual satellites. This increase in the number of satellites highlights the need for collision avoidance manoeuvre management and active debris removal (ADR) technologies to maintain a clean space environment. Airbus have developed and demonstrated a variety of ADR technologies, this paper specifically highlights the harpoon, net and robotic based capture. These technologies are vital to the continued safe use of space, both for commercial and military assets, but there is a possibility for hostile nations to use them maliciously from their own satellites. As an ADR service will be able to detect and capture an uncooperative target, it could be used to target functioning satellites in order to disrupt their service. Satellites are designed to be perfectly balanced in their environment and any changes, such as a thermal imbalance, can have a negative effect on providing its intended capability. Airbus are committed to the safe use of space and are working with agencies to enable these ADR services as well as protect from their misuse.

1.0 INTRODUCTION

The space environment is becoming more and more congested with objects as the number of satellites launched into space is constantly increasing, especially with the introduction of multiple constellations (ESA, 2021). Although space is seemingly large, satellites operate in bands of preferential orbits causing operators to perform multiple collision avoidance manoeuvres each year, dodging both functional satellites and fragments of debris. This has been exacerbated by testing of anti-satellite weapons, causing more fragments and potential threats to operational satellites (SWF, 2010). To enable a sustainable space environment operators must ensure satellites are de-orbited at end of life or moved to a graveyard orbit, this needs to be in parallel to actively removing defunct objects that are unable to remove themselves.

This paper outlines the developments of capture technologies by Airbus that can be assigned to (or used against) small satellites, as well as highlighting potential threats associated with the development of the technologies by hostile nations.

1.1 Airbus Developments

Airbus is a promoter of sustainable space and is part of the advisory group of the World Economic Forum (WEF), which is developing an eco-label for space missions (the Space Sustainability Rating). Airbus is also a member of the Space Safety Coalition lobbying for strengthened Space Law as constellations become a reality. Along with supporting sustainable space accountability there have also been developments on technologies for removing space debris already present in orbit. Many studies and system designs have been performed both internally and with agencies, such as the SpaceTug programme or the Sunrise ADR project. One such project was the RemoveDEBRIS mission seen in Figure 1; a European Commission FP7 funded programme to demonstrate active debris removal (ADR) technologies in orbit. Further detail can be found here (Aglietti, 2019). The 100 kg RemoveDEBRIS mission is not Airbus's only ADR project but provides a good overview of capture systems suitable for small satellites likely found in a constellation. The sections below go into further detail on the payloads developed for RemoveDEBRIS, as well as other building blocks being developed.

Figure 1: RemoveDEBRIS satellite deployed from the ISS in June 2018 (NASA, 2018)

2.0 CAPTURE TECHNOLOGIES

2.1 Harpoon

The RemoveDEBRIS harpoon payload has been designed by Airbus UK to capture targets which do not have a pre-designated capture method. The harpoon is able to puncture a targets structural panel, assuming no major components are installed on the rear of the panel, and uses sprung barbs to secure the capture. Operation of the harpoon is also very simple where only power lines are required to perform the entire firing sequence. The payload heaters are thermostatically controlled with an LM135 temperature sensor to inform the platform when operational temperatures have been reached, upon reaching operational temperature the sprung hinged harpoon door is opened. The harpoon is actuated via two cold gas generators which store nitrogen gas chemically at ambient pressure, upon activation a chemical reaction occurs producing the cold nitrogen and building pressure in the harpoon firing chamber behind a piston. The piston is automatically released once sufficient pressure has been generated via a tear pin, thus enabling consistent firing velocities. In a real capture scenario the target can be manoeuvred post capture via a tethered link connected between the harpoon and the chasing spacecraft; a damping system is also present to dampen unwanted tether dynamics to safely tow the target. Other options for removing the target can include the installation of self-propelling back-packs connected to the harpoon which can perform the necessary disposal manoeuvre.

The harpoon was tested aboard the RemoveDEBRIS satellite in February 2019, the flight harpoon is shown in Figure 2 prior to installation of the multi-layer insulation or installation into the payload assembly enclosure. The demonstration saw the tethered 80g titanium projectile fired at an aluminium composite panel target that had been deployed to a distance of 1.5 m, the honeycomb target panel was representative of the structure used on satellites and had a thickness of around 10 mm. The demonstration was recorded using the satellite platform cameras which revealed an in-orbit firing speed of ~19 m/s and an accuracy of +/- 20 mm, similar to on-ground testing. Figure 3 shows the point of impact during the in-orbit firing, the outer green circle represents the allowable impact area to ensure capture, and the inner grey circle represents the predicted area of impact following testing on ground. Upon impact with the target the panel came away from the boom and revealed the rear-side of the impact. During the in-orbit test the harpoon didn't fully penetrate the target, although this was expected as the target had very little inertia and therefore minimal reaction forces during impact. Despite this the harpoon still provided a secure connection and images following the firing showed the target remained attached to the harpoon. In a real world scenario there would have to be a minimum target inertia in order to allow full capture, however the demonstration showed that even with extremely low target inertia the harpoon was still able to perform a capture without barb deployment. It is estimated that small satellites such as CubeSats could be captured with a harpoon but it wouldn't be practical compared to the other solutions described in the subsequent sections.

Ultimately the harpoon payload was very successful, showing that the small payload of ~10cm x 10cm x 20cm and a mass of ~1kg could be used to capture almost any debris. Due to the nature of the capture system it is better suited to targeting enclosed objects, such as a satellite body, so that any small fragments generated during impact at the exit site are contained within the target enclosure and preventing further generation of debris. Although the current design isn't suited to very small objects it could be adapted to use a smaller and thinner projectile to allow this. Airbus have also designed and tested (on ground) a harpoon capable of capturing large targets with masses of over 8,000 kg. These small payloads could be hosted on constellation satellites as a means of removing defunct satellites from within, or close to, the constellation. Being prepared for harpoon capture, although not necessary, would ease capture and specific capture plates have already been placed on constellations in flight.

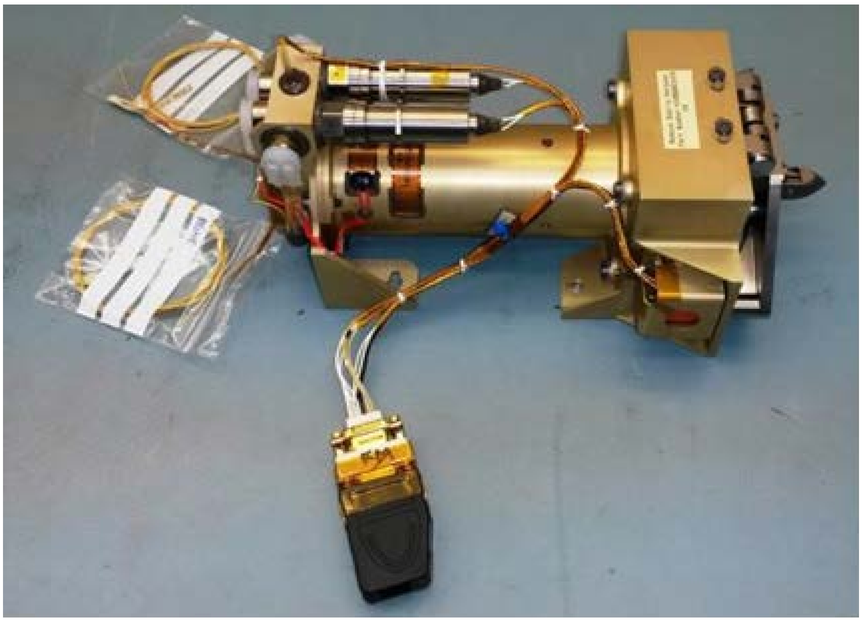

Figure 2: RemoveDEBRIS harpoon prior to installation of multi-layer insulation (Credit: Airbus)

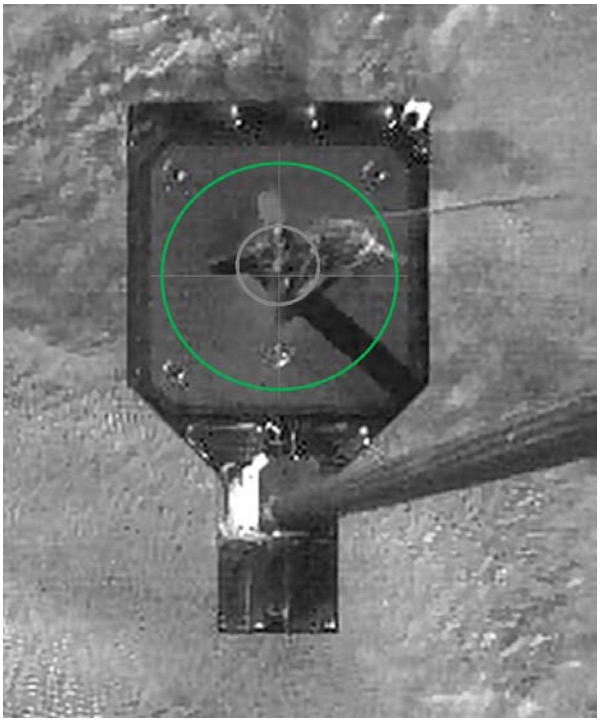

Figure 3: RemoveDEBRIS harpoon payload flight firing. Green circle representing allowable impact area, grey circle representing predicted impact area from ground tests. (Credit: Airbus)

2.2 Net

As with the harpoon design, a net is able to capture targets that do not have a pre-designated capture feature. The RemoveDEBRIS net, designed by Airbus Germany, has a diameter of 5m and encompasses targets upon capture. To deploy the net the hold-down release mechanism on the net canister lid is released, allowing the six sprung throw masses attached to the net perimeter to deploy, as seen in Figure 4. The inertia of these masses draw the net out to its final diameter and cause the net to surround the target upon impact. The masses also house motors, powered by internal super-capacitors, that wind in the perimeter of the net after impact to enclose and secure the target gradually without fragmentation. Once captured the target can be pulled using a tether attached to the net, however for the RemoveDEBRIS mission the net tether wasn’t secured to the main satellite.

The net was the first payload to be demonstrated during the RemoveDEBRIS mission in September 2018, an image of the deployed net during the demonstration can be seen in Figure 4. A dummy target 2U CubeSat was deployed from the RemoveDEBRIS satellite, the CubeSat then inflated booms with Mylar drag sails attached once it had reached a sufficient distance away. The sails served two purposes, they provided a larger target for the net to capture, and also increased the targets surface area to ensure it would naturally deorbit within 5 years of deployment (not becoming debris itself). The net demonstration sequence was controlled using pre-defined timers to minimise risk of missing the target and allowing the target to fully inflate. The net expanded to a total of 4m of its 5m total diameter and captured the target at a distance of around 11m instead of the estimated 7m. This was due to an unexpected increased deployment velocity of the target and a rupture in the inflatable target booms, causing the target to veer off course. However, the net was still able to successful capture the target during the test proving the robustness of the design.

The net payload is very compact and scalable allowing it to fit on small satellites but capture large objects. It can be hosted on smaller satellites but has a larger size/mass compared to the harpoon, as seen in Figure 5, with a volume of ~30 cm x 30 cm x 25 cm and a mass of 6 kg. A minimum target mass isn’t required as the net is able to close itself around the target, there also isn't the same limitation on clear panels to target as there is with the harpoon with the main limitation being the external volume of the target.

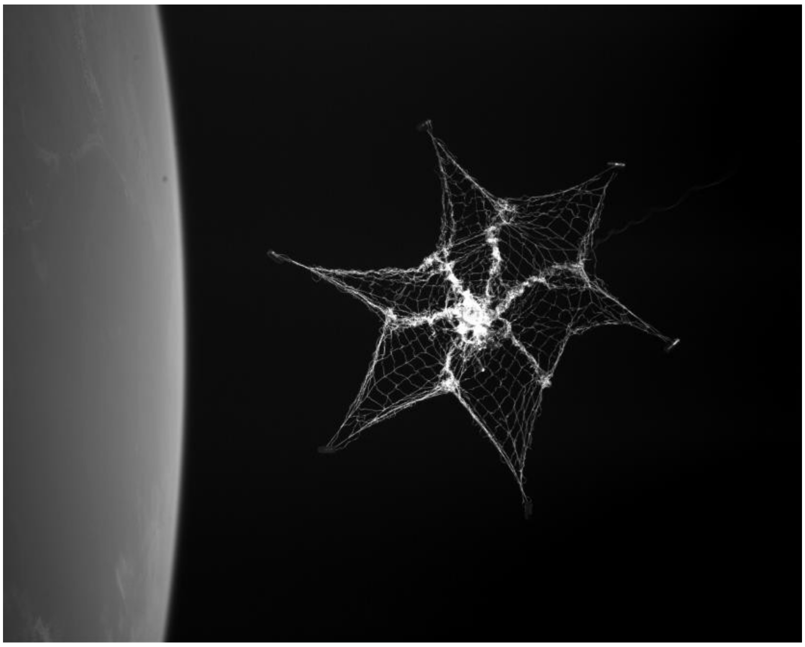

Figure 4: RemoveDEBRIS net payload demonstration (Credit: Airbus)

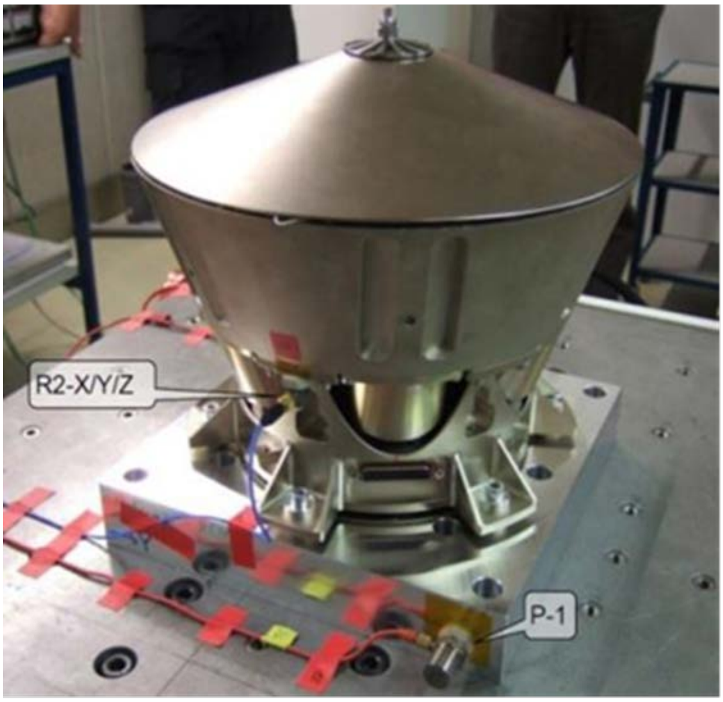

Figure 5: RemoveDEBRIS net payload prior to installation of multi-layer insulation (Credit: Airbus)

2.3 Robotic Arm

Alongside the payloads tested in RemoveDEBRIS Airbus UK have been developing space qualified robotic manipulators and other robotic systems for markets such as in-orbit servicing and ADR. A selection of the arms with some basic specifications can be seen in Figure 6. For ADR a robotic arm can be used as a tool to manipulate a capture tool, securing the target either using a dedicated grapple point on the target, a commonly found standard interface (e.g. a satellite launch adapter ring), or through other means to secure a connection between the arm and the target (such as a magnetic or adhesive capture). Robotic arms for space are generally seen as expensive and heavy, however Airbus have developed a lightweight, low cost, and modular arm for a variety of tasks. One major challenge with ADR is that almost all defunct objects are tumbling with rates of up to multiple degrees per second. During a recent Airbus study the dynamics of a tumbling target were analysed and shown that a robotic arm is able to track and compensate for the tumbling motions of more than 4 degrees per second, capturing a target with minimal manoeuvrability required from the satellite platform. This is desirable as performing full rate matching of the chaser and the target, i.e. tracking a single point, is fuel expensive. As propellant is a finite resource minimising the burn during a capture allows for more targets to be serviced.

As the arms are modular and formed of individual joints and limbs they can be easily adapted to any size of satellite platform, by tailoring the size of the joint (driven by the motor/torque requirements) and the length of the limbs, bespoke solutions can be created with minimal additional cost. New control techniques, such as visual servoing and compliance control, allow lighter and cheaper arms to be used compared to traditional arms that require tight position tolerances for accurate control. These developments alongside the reduction in hardware cost have enabled the increased use of robotics in space and integration of robotic arms on smaller platforms for activities such as ADR. Housing robotics on satellites, especially constellations, allow for multiple use-cases including repair and deterrence, and is not limited to ADR.

Figure 6: Airbus robotic arms for in-orbit servicing showing the development year, total reach, and mass of each arm (Credit: Airbus)

2.4 Capture Assistance

It is extremely difficult to rendezvous and capture a target that is un-cooperative; as such there are a few measures that can be implemented in order to aid post-mission disposal in the event of a failure. One of the main challenges is not having a set interface to use as a capture point. Currently there isn't a standardised ADR interface for satellites, therefore each ADR mission has to use a bespoke capture method which is costly. Companies such as OneWeb have chosen to include specific grapple fixtures with fiducial markers on their satellites to simplify an ADR mission if it was ever required. Including a fixture with suitable fiducial markers or reflectors should be a minimum consideration for new objects being launched into orbit.

Another challenge is that objects left un-controlled in orbit begin to tumble over time, this is due to the build-up of a variety of forces (e.g. solar radiation pressure). This tumbling can be damped by the incorporation of a passive de-tumble device, such as short-circuiting magnetorquers on a LEO spacecraft. Reducing the tumbling rates of debris means that tracking algorithms can be more robust and allows for simplified capture dynamics. Other considerations include specific ADR modes that ensure that targets are prepared to be captured and won't actively fight capture (i.e. anti-cooperative). This can be an issue where defunct targets are stuck in safe mode, usually sun pointing, and any capture could result in a collision between the two spacecraft.

A more novel technique to support ADR includes the addition of an aircraft "black box" style device that can continue operating for a limited time upon satellite failure. This would enable it to broadcast the satellites position and provide short range communications to support rendezvous as well as supporting collision manoeuvres for other operation spacecraft.

3.0 DUAL USE ACTIVE DEBRIS REMOVAL

3.1 Vulnerability to ADR Technology

ADR is an attractive dual-purpose system, providing nations the ability to show responsible environment stewardship by removing failed space assets whilst also demonstrating the technical capability to interdict competitor spacecraft. Possessing an ADR capability can therefore be viewed as a means of protection, either by proactively responding to a hostile approach, or just as a passive deterrent through assuring reciprocal action. As ADR allows the capture of an un-cooperative target it can be classified as a threat but the lines are blurred between whether a servicing technology capability is hostile or not. The threat of a direct ascent anti- satellite weapon (ASAT) is broadly understood, and attributable to few nation states; however ADR can be developed by both commercial and military users. The technology may be used directly or indirectly to intervene, interdict, or otherwise disrupt scheduled operations of military satellites, whether those operations are data collection and dissemination, or routine communication links. It is not necessary to fully dispose of a space asset to render it ineffective. For example, manoeuvring and attaching an object to another spacecraft will disrupt the target's moment of inertia sufficiently that the target's AOCS control laws will be unable to maintain pointing budgets. This could effectively remove an intelligence, surveillance and reconnaissance (ISR) capability without appreciably increasing the existing space debris population and therefore avoiding the international reaction that may result from ASAT use. If this type of attack were to be performed using a stealth-equipped asset, it would be difficult for operators to isolate the cause and understand the source of the problem.

There are a number of operational budgets that may be attacked using ADR type technologies. Power and thermal budgets may be compromised by deployment of a net with solar shading or thermally reflective material, link budgets can be disrupted by using the ADR craft's own transceivers as jamming sources. Another danger is that an ADR satellite will have the ability to wait in a parking orbit, appearing seemingly innocent until commanded to approach.

Possible co-orbital threats have already be identified though with no official indication of an ADR capability. Satellites such as Luch and SJ-17 have attracted attention by shifting position within the GEO belt on a relatively frequent basis (Harrison et al., 2021). Approaching satellites in this manner could allow for close inspection or potentially interception of their communication links, and if such a satellite were to have ADR capabilities, as likely demonstrated by SY-7 with a robotic capture of a target (SWF, 2018), the threat would be even greater. With the rapid developments of ADR it must therefore be assumed that competitors have the capability to rendezvous and disrupt assets and as such this must be protected against.

3.2 Resistances to Unwanted ADR

A key technology requirement for an effective kinetic physical attack is the ability to detect, track and guide the hostile platform to the correct satellite target. The primary source for guidance towards the target satellite would be acquired using space situational awareness (SSA) systems, the sources are shown below in Figure 7. The majority of these are ground based systems using radar, optics, intercepted RF signals or lasers. However, there is also the possibility of using space-based SSA capabilities. Multiple different types of SSA measurements are required in order to accurately determine a satellite's ephemeris in order to predict its future motion. This involves a considerable degree of monitoring of the target satellite, verifying it is the correct target, and ensuring successful interception.

Countermeasure payloads with the capability to identify when the host platform is being illuminated would give vital information here. These type of payloads coupled with the ability to attribute unwanted ADR action would be a strong asset in the resistance of these actions. Additionally, the use of a bodyguard satellite to intercept these actions gives wider countermeasure capabilities and acts as a strong deterrent. In essence, robust space situational awareness is required to monitor approaches and ensure accountability of actions.

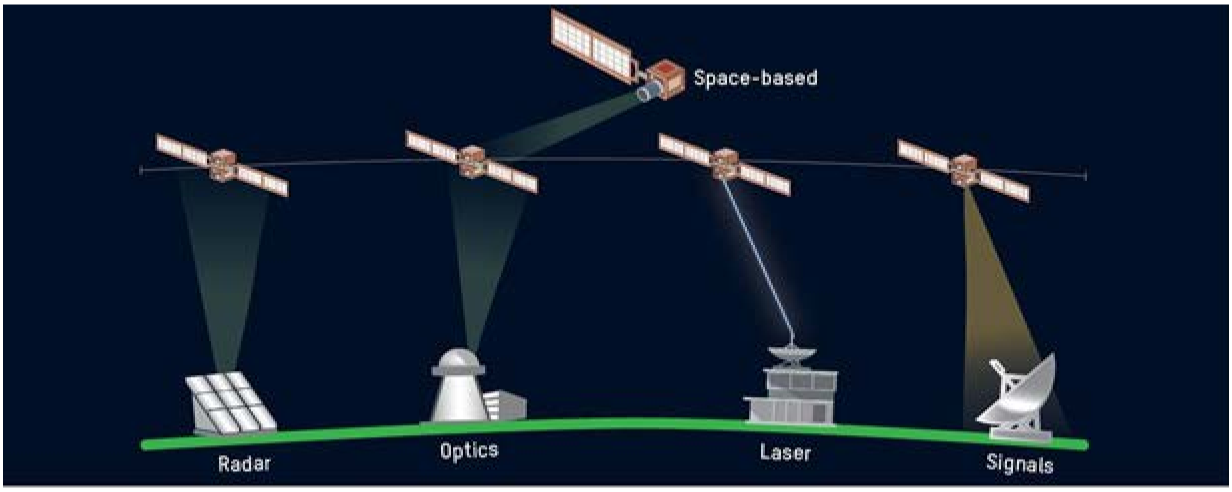

Figure 7: Five types of SSA capabilities (Defence Intelligence Agency, 2019)

3.3 Resilience of Constellation Architecture

As ADR technology is becoming increasingly available, the likelihood of it being used by a hostile nation is also increasing. Countermeasures can be employed but monitoring is only as good as the available sensors and supporting algorithms; satellite stealth technology and techniques may still allow evasion of detection and enable exploitation of a vulnerability. Ultimately, deterrence of hostile ADR would likely rely on making its use too costly; either by demonstrating reliable attribution or by rendering it financially unviable.

Demonstration of unequivocal detection and tracking techniques would support the narrative of effective and reliable attribution, establishing in-orbit truth. This would require growing capability in both sensors and algorithms; the former for improved and novel methods of detection, the latter to achieve sensor data fusion and target tracking. These technologies and techniques may be developed under the umbrella of combatting the growing issues with space debris, but would be clearly transferrable to the contested space domain. This would provide support to national and international discourse aimed at dissuading competitors or adversaries from investing or engaging in disruptive ADR technology.

Rendering hostile ADR actions financially unviable could also be achieved through disrupting the value-balance of action and effect. For example, deploying a small cheap satellite to interdict and disrupt an expensive single asset is a financially attractive course of action. On the other hand having to deploy tens of similar satellites against a constellations of satellites is less so. In this context, increased resilience of small satellites for military use may be derived from cheap, rapidly replaceable platforms supported by responsive launch, where economies of scale come into effect and non-recoverable costs are spread across multiple platforms. Deployment of advanced inter-satellite links (ISLs) to support a constellation-level service can be used to enhance connectivity in non-contested domain operations, it would also enable fall-back coverage in the case of loss of an asset to ADR or technical failure. This would reduce the impact of hostile ADR actions from complete loss of service, to merely temporary degradation of service.

ISL-enabled constellations would also enhance resilience in the ground segment. Transportation of data through a space segment to geographically diverse ground stations would protect downlink capabilities from threats due to ground-based interdiction through jamming or direct attack, as any disrupting action would have to occur simultaneously at multiple ground sites.

4.0 CONCLUSION

Space is becoming increasingly crowded and there is the need for ADR technologies to ensure space sustainability, this comes with a risk as the technologies are adopted for dual-use purposes. Airbus is developing a wide range of technologies that can be used for ADR, some of the capture technologies being developed have been presented above. Although capturing the target is just one aspect of an ADR mission it is a crucial element that is one of the riskiest tasks of the mission. To aid this manufacturers and operators can incorporate certain features to simplify the mission, thereby reducing overall mission cost.

As the technology becomes widely available there is also the need to protect against possible hostile ADR acts in space. This can be managed both through in-orbit technologies for protection, as well as diplomacy actions on ground. Employing a combination of countermeasure payloads and unequivocal accountability of actions can reduce the risk of a threat ever occurring. This is especially critical as any action in space that generates debris is a detriment to all space faring nations, for both commercial and military markets.

Increased resilience against threats can also be accomplished through the use of constellations, where performance is spread across a multitude of platforms rather than a singular target. This ensures that any hostile action may degrade payload performance on one platform but a service is maintained due to the distributed payloads, thereby dissuading any attack at all. All these aspects need to be considered when designing missions and appropriate trades need to be made on the incorporation of ADR assistive technologies such as capture features and fiducial markers for post-mission disposal, both to assist genuine servicing and to prevent hostile misuse of the features.

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