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Full Report

# In-Orbit Services

## Policy and Business Perspectives

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# 1 INTRODUCTION

## 1.1 Defining in-orbit services

Since the launch of Sputnik in 1957, space systems have been built to be operational over their entire mission life cycle without human or physical intervention. For a long time, the possibility to autonomously upgrade, repair, reposition or refuel a satellite in orbit was only a utopia for space operators and manufacturers. However, with innovation and technical progress, In-Orbit services are the object of a renewed interest and could reach a higher level of technological readiness in the coming years. Whilst many challenges remain, this nascent and disruptive activity is often described as a game changer since it has the potential to significantly modify the way space systems are designed, manufactured and operated.[1]

Indeed, In-Orbit services (IOS) encompasses a wide scope of new activities conducted in outer space and addresses an even broader range of technical, technological, industrial, legal and political challenges. Although it is increasingly discussed in the space community, there is no official, comprehensive or universally accepted definition of In-Orbit services, which are sometimes called On-Orbit services or In-Space services.

In-Orbit services require space rendezvous and close proximity operations, which could be defined as *"orbital manoeuvres in which two spacecraft arrive at the same orbit and approach at a close distance"*.[2] Close proximity operations usually imply that the two space systems are within a few kilometers or less from each other. The main distinction with in-orbit services is the contact and/or communication established with the other spacecraft following the space rendezvous in order to conduct maintenance, inspection or towing.

Jean-Marie Bourjolly et al. (2006) defined In-Orbit services as *"the robotic capability of maintaining and repairing satellites … by providing added operational flexibility through services such as refuelling, repair operations and orbital correction manoeuvres"*[3] , and DARPA described in-Orbit services as the use of *"robotic vehicles to physically inspect, assist, and modify on-orbit assets."*[4]

According to Anne-Sophie Martin, from the Sapienza University of Rome, in-orbit services consist in *"a focused action, through a space tug in order to maintain, repair, upgrade, refuel or de-orbit a spacecraft while it is in orbit. These activities require the service spacecraft to approach, rendezvous and interoperate with the space asset to another State, Agency or private company"*[5]. This definition mainly outlines the

[1] Bourjolly, J. and Gurtuna, O., 2006. On-Orbit Servicing: A Time-Dependent, Moving-Target Traveling Salesman Problem. [online] International Transactions in Operational Research. Available at: <https://www.researchgate.net/publication/229744321_On-orbit_servicing_A_time-dependent_moving-target_traveling_salesman_problem> [Accessed 26 November 2020].
[2] Reesman, R. and et al, 2018. Getting In Your Space: Learning From Past Rendezvous And Proximity Operations. [online] Aerospace Corporation. Available at: <https://aerospace.org/sites/default/files/2018-05/GettingInYourSpace.pdf> [Accessed 24 November 2020].
[3] J.-M. Bourjolly et al. /Intl. Trans. in Op. Res. 13 (2006) p.463
[4] Darpa. n.d. Consortium For Execution Of Rendezvous And Servicing Operations (CONFERS). [online] Available at: <https://www.darpa.mil/program/consortium-for-execution-of-rendezvous-and-servicing-operations> [Accessed 27 November 2020].
[5] Martin, A., 2020. Legal Approach on the Dual-Use Nature of On-Orbit Servicing Programs, in: Froehlich, A., 2020. On-Orbit Servicing: next Generation of Space Activities, ESPI, Springer, p.1

tools (space tug) and the different phases of in-orbit services, namely rendezvous, docking, joint manoeuvres and undocking.[6]

Sara Carioscia et al (2018) from the Institute for Defence Analyses provided a functional and pragmatic definition of IOS *"servicing is defined as the on-orbit alteration of a satellite after its initial launch, using another spacecraft to conduct these alterations."*[7]

According to Joshua Davis, from the Aerospace Corporation, in-orbit services can be defined as *"on-orbit activities conducted by a space vehicle that performs up-close inspection of, or results in intentional and beneficial changes to, another resident space object (RSO). These activities include non-contact support, orbit modification (relocation) and maintenance, refuelling and commodities replenishment, upgrade, repair, assembly, and debris mitigation."*[8] This definition mainly highlights positive and cooperative aspects between the servicer (the system providing the in-orbit service) and the serviced space object (the system receiving the in-orbit service).

However, In-Orbit Services were first envisioned for military purposes[9] and the serviced spacecraft can also be a non-cooperative target as it is outlined in the definition of Heike Benninghoff and Toralf Boge from DLR: *"In on-orbit servicing missions, a service spacecraft approaches a non-cooperative, passive target spacecraft in its orbit to perform service tasks … A typical non-cooperative target satellite is neither equipped with reflectors or markers which can be used for relative navigation, nor has specially intended grasping/docking equipment for robotic capture. There is no communication between servicing and target satellite or between ground station and target."*[10]

These definitions highlight the large scope of activities of in-orbit services which are actually part of a broader set of in-orbit operations defined as a group of concepts and activities involving advanced support operations taking place in outer space.

#### In-Orbit Operations comprise:

- In-Orbit servicing which refer to the provision of support services by a spacecraft (servicer) to another space object (serviced) while in orbit;
- In-Orbit Manufacturing which are defined as the use of innovative techniques, such as space resources or 3D printers, to build items and components directly in outer space;
- In-Orbit Assembly which is characterized as the assembly or combination of modular platforms to form a new object as well as the integration of upgrade payloads in orbit.

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[6] Jewison, C., 2017. Guidance and Control for Multi-stage Rendezvous and Docking Operations in the Presence of Uncertainty, MIT, p.40

[7] Carioscia, S. and et al, 2018. Roundtable Proceedings: Ways Forward For On-Orbit Servicing, Assembly, And Manufacturing (OSAM) Of Spacecraft. [online] Institute for Defense Analyses. Available at: <https://www.ida.org/-/media/feature/publications/r/ro/roundtable-proceedings-ways-forward-for-on-orbit-servicing/d-10445.ashx> [Accessed 27 November 2020].

[8] Davis, J. and et al, 2019. On-Orbit Servicing: Inspection, Repair, Refuel, Upgrade, And Assembly Of Satellites In Space. [online] Aerospace Corporation. Available at: <https://aerospace.org/sites/default/files/2019-05/Davis-Mayberry-Penn_OOS_04242019.pdf> [Accessed 23 November 2020].

[9] ESPI. 2020. In-Orbit Servicing: Challenges and Implications of an Emerging Capability. ESPI Brief 38

[10] Benninghoff, H. and Boge, T., n.d. Rendezvous Involving A Non-Cooperative, Tumbling Target - Estimation Of Moments Of Inertia And Center Of Mass Of An Unknown Target. [online] ISSFD. Available at: <https://issfd.org/2015/files/downloads/papers/007_Benninghoff.pdf> [Accessed 23 November 2020].

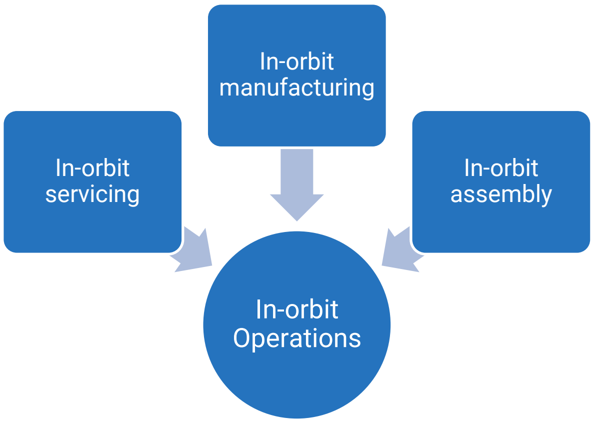


*Figure 1: Category structure of In-Orbit Operations*

The collection of several definitions of In-Orbit Operations enables to identify several categories of orbital services such as, but not limited to, maintenance, tugging and inspection:

**Maintenance**

- **Repair**: repairing or replacing parts of a space system in orbit in order to extend or maintain the system in operational conditions.
- **Reconfiguration**: modifying the spacecraft's payloads or modules in order to repurpose the mission of a space sytem.
- **Refuelling**: providing and transferring propellant, fuel pressurants or coolants from the servicer spacecraft to the target one, in order to keep the system operational.
- **Recharging**: providing electric power to a satellite in orbit through power beaming or docking
- **Upgrade**: replacing or adding components to a space system to improve its capabilities.

**Tugging and Towing**

- **Station-keeping:** docking of the servicer spacecraft with a target satellite in order to keep the target in a particular orbit or attitude.
- **Orbit correction:** relocating or repositioning a space system to the adequate orbit.
- **Relocation**: modifying the position of the space system
- **De-orbiting:** capturing a space system to relocate it to a graveyard orbit or to accelerate its atmospheric re-entry.
- **Recycling**: retrieving the raw materials of orbiting rocket bodies to transform them into other space components or products.

**Inspection**

- **In-orbit inspection:** assessing the physical status and conditions of a satellite and potentially detecting anomalies or examining the consequences of an attack or collision.

*Figure 2: Types of in-orbit services*

Today, in-orbit services and their key enabling technologies are seen as providing benefits to various space activities such as science, exploration, national security, space safety and commercial missions.

In-orbit assembly can enable the creation of large infrastructure in orbit that cannot be assembled before launch due to their weight, volume, size or structure. This activity will be particularly useful to sustain a permanent presence in space and on the Moon and will give satellite manufacturers more flexibility in the design of space systems.

While in-orbit services will require better space situational awareness to be operational, in-orbit services can improve SSA capabilities as in-orbit inspections, maintenance and tugging will provide additional data about space objects. In-orbit services can also enhance debris management through active debris removal.

In addition, in-orbit services will allow operators to refuel satellites when they run out of propellant and relocate them in the appropriate orbit in case they are drifting, thereby extending their life. In-orbit services can also enable operators to wait until their satellites are out of propellant and/or out of service to relocate them to the graveyard orbit for GEO satellites or through re-entry into the Earth's atmosphere for LEO satellites. At the moment, operators still have to save a certain amount of propellant to conduct this activity. As a result, relocation and refuelling can extend the life of satellites and maximize economic benefits.

Moreover, in-orbit services can restore or repair parts that got damaged or did not deploy correctly after launch such as solar panels. These failures can significantly reduce the lifetime of the satellite or render it inoperable from the start of their mission. With in-orbit services, robotic arms could allow the correct deployment of the solar arrays after separation from the launcher. Also, a spacecraft could provide additional power to the solar arrays through power beaming.

Furthermore, maintenance and reconfiguration could provide operators with the means to modify payloads and repurpose the mission of a satellite instead of launching a new one. Therefore, in-orbit services can improve mission flexibility and reduce costs while contributing to the reduction of the number of objects in orbit.

However, the concept of in-orbit services raises a growing number of questions regarding the technical feasibility, business profitability, competitiveness as well as legal and military issues for activities that do not have a regulatory framework or standards yet.

## 1.2 Objective of the report and rationale

### 1.2.1 Objective of the report

The objective of this research is to provide a comprehensive definition and assessment of the commercial and institutional landscape of in-orbit services as well as an overview of the various technological, technical, economic, political and legal challenges surrounding this technology. Specifically, this report aims at investigating and analysing the role of European public actors with regard to in-orbit services.

### 1.2.2 Rationale

Indeed, it is mainly the efforts of public actors that has led the development of in-orbit servicing over time. Although a few European companies have been involved in some IOS projects or have developed some systems, the development of industrial capabilities in this domain has not been perceived as a top priority by European public actors over the last decades. In addition, the first fully commercial initiative reported to date was launched just four years ago in the United States.

Technologies for in-orbit services have been slowly developing since the 1970s and it is now deemed achievable at large scale in a foreseeable future. Although technical, legal, political and economic challenges remain, there seems to be no major blocking points or showstopper for the development of in-orbit servicing facilities. However, beyond the challenge for in-orbit servicing to reach a sufficient Technological Readiness Level, to be economically viable, market demand, opportunities and interests from the space sector still need to be confirmed. In this respect, public actors, either at the national or European level, can play an important role to enable and sponsor this technology, establish standards and boost the demand for in-orbit servicing beyond the basic economic stimulus, especially in the following domains:

- Sustainability and Security: In-orbit services and close proximity operations are at the crossroads of Space Situational Awareness and Space Traffic Management with technologies such as Active Debris Removal, In-Orbit Inspections and life extension. While in-orbit services can enable debris management, these highly manoeuvre-intensive activities can also trigger collisions in already contested and crowded orbits. It can be anticipated here a role for public actors to ensure the sustainability of the space domain through various means, including proper control, oversight and exploitation of in-orbit services.
- Peaceful use of outer space: In-orbit services are also dual-use technologies and could potentially be used as in-orbit counterspace weapons which are the subject of legal, diplomatic and political tense discussions.
- Future exploration missions: Moon, Mars or Deep Space missions will probably take advantage of in-orbit services capabilities because of their nature or technical architecture, which could in turn trigger a demand sustained by future national or international exploration programmes.

The action of public actors could be a game changer in the development of IOS. The first actors to take a dominant position in this domain have more chances to develop national and international standards that fit their political and industrial interests. As a result, if Europe wants to remain a significant actor in global space efforts, it is important for governmental and industrial actors not to miss this technological breakthrough.

# 2 STATUS: CONCEPTS AND PROGRAMMES

## 2.1 Historical Perspective

### 2.1.1 The pre-ISS era

Space rendezvous and close proximity operations, which are pre-requisite for in-orbit services, have been tested since the 1960s:

- Indeed, the first successful space rendezvous was demonstrated in 1965 when Gemini 6 approached and maintained a distance of only 30 cm with Gemini 7. According to Christopher Michael Jewison from the MIT, in the beginning, the Soviet Union had an automated approach to space rendezvous and docking (first autonomous docking between Cosmos 186 and Cosmos 188 in 1967[11]) while the United States had more of a manual approach, using Extravehicular Activities.[12]
- The first In-Orbit servicing mission was conducted by the United States during the second Skylab mission in 1973. It consisted in a maintenance mission to repair the failed deployment of solar arrays and the micrometeoroid protection (thermal management).
- In 1984, the Palapa B2 satellite, owned by the Indonesian government, and Westar 6, owned by Western Union, failed to reach GEO and were retrieved and brought back to Earth.
- In 1993, the first servicing mission demonstrated the repair of the Space Hubble's damaged telescope as well as the replacement of solar arrays, magnetometers and sensors in orbit.
- In 1997, the second servicing mission was an upgrading mission in which "second generation" components were installed to enhance the productivity of Hubble to perform scientific measurements.
- Then, in 1999, the third servicing mission (Discovery) to Hubble was a repair and maintenance mission that replaced damaged gyroscopes. It was also an in-orbit assembly mission with the installation of New Outer Blanker Layers (NOBLs) which were used to manage the temperature on board.
- Finally, in 2002, Servicing Mission 3B (Columbia) was an in-orbit assembly mission that upgraded Hubble through the replacement of the power control unit and the installation of Advanced Camera for Surveys, new solar arrays and a cooling system.[13]

These in-orbit missions were conducted only by nation states, namely the US and the Soviet Union. They were conducted on systems that were not designed to be serviced and almost always involved human spacewalks or Extravehicular Activities.14 These missions were either technical experiments conducted prior to bigger missions (such as Apollo) or operations undertaken by necessity to maintain space systems operational because the technology at the time did not allow other alternatives.[15]

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[11] Garcia, M., 2017. 50 Years Ago: The First Automatic Docking In Space. [online] NASA. Available at: <https://www.nasa.gov/feature/50-years-ago-the-first-automatic-docking-in-space> [Accessed 26 November 2020].
[12] Jewison, C., 2017. Op cit. p.37
[13] NASA. 2010. On-Orbit Satellite Servicing Study Project Report. [online] Available at: <https://nexis.gsfc.nasa.gov/images/NASA_Satellite%20Servicing_Project_Report_0511.pdf> [Accessed 27 November 2020].
[14] Tatsch, A. and et al, 2006. On-Orbit Servicing: A Brief Survey. [online] Performance Metrics For Intelligent Systems Workshop, National Institute of Standards and Technology. Available at: <https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication1062.pdf#page=278> [Accessed 27 November 2020].
[15] Krafft, E., 1663. Orbital Operations, Advances in Space Science and technology Volume 5, p.231-325

### 2.1.2 The ISS era

The ISS is a great example of the usefulness and potential of In-Orbit Operations with:

- The assembly of Unity and Zarya modules in 1998,
- The Zvesda module in 2000,
- The installation of the Destiny Lab module and the Russian Piers airlock in 2001,
- Among other extravehicular activities.[16]

During this period:

- In 1997, the National Space Development Agency of Japan (NASDA) launched ETS-VII and demonstrated the first space rendezvous and docking between two space systems through a 2m robotic arm,
- In 2003, the US Air Force launched the microsatellite XSS-10 which conducted in-orbit inspections of its own second stage and the XSS-11 which demonstrated autonomous close proximity operations by approaching and taking images of other US satellites,
- In 2005, NASA launched the Demonstration of Autonomous Rendezvous Technology (DART) mission which was a rendezvous operation that failed and led to collision,
- In 2007, DARPA launched the Orbital Express mission which demonstrated autonomous docking, fuel transfer and the insertion of batteries.[17]

These missions were less costly, more autonomous and relied on more robotics than during the pre-ISS era but still required some level of human intervention. According to Joshua Davis, it is mostly the efforts made by public actors such as NASA that led to the development of in-orbit services.[18]

### 2.1.3 Other state actors in in-orbit services

The ConeXpress Orbital Life Extension Vehicle that was supposed to launch in 2010 but was cancelled after Dutch Space opted out of the project.[19] The same year, the PRISMA mission led by the Swedish National Space Board (SNSB) was launched and demonstrated close proximity operations and manoeuvres through Guidance, Navigation and Control.[20] In 2017, DLR launched the iBoss (intelligent Building Blocks for On-Orbit Satellite Servicing and Assembly) to demonstrate In-Orbit Assembly and more particularly reconfiguration and expansion.[21]

In 2016, Russia conducted close proximity operations with its systems Kosmos-2941, Kosmos-24-99 and Kosmos-2504 around debris before going dormant. Then, from July 2017 to November 2018, the Russian satellite Luch-Olymp conducted unwelcomed close proximity operations next to the French-Italian military satellite Athena-Fidus.[22] The two space systems were within 5 kilometres from each other but the approach would have been close enough for the Russian satellites to receive RF communications had

[16] Leete, S., n.d. DESIGN FOR ON-ORBIT SPACECRAFT SERVICING. [online] NASA. Available at: <http://www.dept.aoe.vt.edu/~cdhall/courses/aoe4065/OtherPubs/designforonorbitservicing.pdf> [Accessed 27 November 2020].
[17] NASA. 2010. Op cit.
[18] Davis, J. and et al, 2019. Op cit.
[19] Gunter's Space Page. 2017. Conexpress-OLEV (CX-OLEV). [online] Available at: <https://space.skyrocket.de/doc_sdat/conexpress-ors.htm> [Accessed 27 November 2020].
[20] ESA. n.d. PRISMA (Prototype) - Eoportal Directory - Satellite Missions. [online] Available at: <https://earth.esa.int/web/eoportal/satellite-missions/p/prisma-prototype> [Accessed 27 November 2020].
[21] DLR. n.d. BOSS – Intelligent Building Blocks For On-Orbit Satellite Servicing And Assembly. [online] Available at: <http://www.iboss-satellites.com/fileadmin/Templates/iBOSS_Satellites/Media/iBOSS_Concept.pdf> [Accessed 27 November 2020].
[22] Roberts, T., 2020. Unusual Behavior In GEO: Luch (Olymp-K). [online] Aerospace Security, CSIS. Available at: <https://aerospace.csis.org/data/unusual-behavior-in-geo-olymp-k/> [Accessed 27 November 2020].

France not taken preventive measures.[23] These manoeuvres did not involve docking or maintenance or inspection operations but are supposedly look like close proximity operations next to a non-cooperative target for intelligence purposes.

In the same vein, in 2010, China launched the satellite SJ-12 and demonstrated close proximity operations next to another Chinese satellite. This experiment was considered by the US as an in-orbit jamming test. In-Orbit operations seems to be a priority for the Chinese government as it conducted several missions. Indeed, in 2001, the Shenzhou-9 space capsule docked with the Tiangong-1 space station. Then, in 2013, China launched three satellites and demonstrated maintenance operations. In 2016, China launched Aolong 1 to demonstrate the first removal of a space debris with a robotic arm. It also launched a satellite as part of the mission and demonstrated in-orbit refuelling.[24]

These examples are uncrewed autonomous activities which are controlled remotely by operators. However, it is important to note that at the moment, in-orbit services have not yet reached technological maturity and the aforementioned examples are still state-sponsored missions. Commercial in-orbit services actually emerged with the very first fully commercial servicing mission launched in 2019 by a subsidiary of Northrop Grumman.

## 2.2 Drivers behind in-orbit services

### 2.2.1 Institutional drivers: the public sector as the traditional enabler of in-orbit services

To date, the possibilities and activities potentially offered by IOS are well suited for various governmental missions. In addition, several factors could boost the institutional demand for in-orbit services.

One major institutional driver behind in-orbit services is space sustainability and the increasing pressure to tackle the issue of space debris in crowded orbits. In the past few years, some States have expressed their willingness to act on the matter either through legal means by prohibiting or regulating the creation of debris, or through technological means such as enhanced Space Traffic Management and Space Situational Awareness, Active Debris Removal or life extension.

At the same time, too much debris could prevent the safe execution of in-orbit services. Better space domain awareness is essential to allow safe and affordable in-orbit operations that might prevent operators to reach a graveyard orbit prior to IOS delivery for collision-avoidance purposes. Recently, the EU and EU Member States have outlined the necessity to improve European capabilities in the field of SSA and STM, which might foster the development of IOS and enhance their reliability. In-orbit services on the other hand could complete existing SSA capabilities by enabling to take pictures of the surrounding environment, conduct in-orbit inspections and provide additional data on space objects.

Furthermore, the concerns related to the weaponization of outer space could fuel a strong institutional demand for in-orbit services. Space systems could be damaged by an adversary's spacecraft and require maintenance and repair operations in order to be kept in operational conditions. An intentional collision between two space objects could also increase the demand for debris de-orbiting. In addition, a cyberattack on a satellite can lead a system to turn its solar panel in the wrong direction, drift to the wrong

[23] Ministere des Armees. 2019. Discours De Florence Parly_Présentation De La Stratégie Spatiale De Défense. [online] Available at: <https://www.defense.gouv.fr/salle-de-presse/discours/discours-de-florence-parly/discours-de-florence-parly_presentation-de-la-strategie-spatiale-de-defense> [Accessed 27 November 2020].
[24] Harrison, T. and et al, 2019. Space Threat Assessment 2019. [online] CSIS. Available at: <https://aerospace.csis.org/wp-content/uploads/2019/04/SpaceThreatAssessment2019-compressed.pdf> [Accessed 27 November 2020].

orbit, waste its propellant or disable critical settings. Such types of attacks could increase the demand for recharging, refuelling, orbit correction or relocation. In addition, the inherently dual aspect of IOS technologies could raise interest of some governmental actors in the perspective of a potential outer space warfare.

The perspective of collisions or conflicts in outer space could speed up institutional investments or regulations but might also deter commercial investments. Also, the development of international standards and/or regulations could either make or break the case of IOS. However, the establishment of international standards for debris removal and satellites' end of life could increase the demand for IOS.

Moreover, another driver behind the development of in-orbit services is the renewed interest in space exploration with goals to establish permanent presence on the Moon or even Mars. These missions will require on-orbit assembly for building large and complex infrastructures such as the US Lunar Gateaway. Current developments in space mining as well as legal initiatives regarding space resource appropriation in the US, Luxembourg and the UAE might also increase the demand for in-orbit manufacturing.
Finally, institutional programmes can stimulate the demand for in-orbit services as public institutions are trusted and possibly anchor-customers that can help make the case for such technologies and systems and encourage private companies to consider this market.

### 2.2.2 Commercial drivers: a profitable business still unexplored by New Space?

While in-orbit services have mostly been so far the prerogative of governmental actors, some fully commercial initiatives have emerged in the last few years, indicating an increased interest in IOS. These commercial developments can be explained by factors such as but not limited to:

- Reduced launching costs and rising commercial launch capabilities can enable state actors and private companies to launch more affordable and cost-effective in-orbit services.
- Increased number of space systems in orbit, in particular large satellite constellations will create a high market demand for maintenance, repair and de-orbiting services in the next decades.
- Easier access to venture capital and private funding can enable an easier development of in-orbit services and give the possibility to start-ups to demonstrate their innovative technologies and enter this emerging business more easily.
- Lack of restraining regulations, standardization or international framework allow space companies to develop innovative systems for in-orbit operations with reduced constraints.
- Increased availability of public and private SSA data can make the demonstration of in-orbit services more secure and enhance companies and investors' confidence in the feasibility and profitability of IOS.
- Emergence of Open Source Satellite OS such as NASA Core Flight System or Satellite-as-Service (SaaS) are meant to enable start-ups that do not benefit from the expertise or experience of established space companies to mostly focus on mission specific applications related to IOS and accelerate the development of their system and their entry to market.

Furthermore, commercial initiatives have been slow to emerge due to debates about the feasibility and reliability of IOS, technological challenges as well as the absence of a clear profitable business case for IOS. However, the success of the Mission Extension Vehicle (MEV) commissioned by Intelsat can create a ripple effect and encourage startups to enter this market or established space companies to develop IOS technologies. According to a study conducted by the Institute for Defense Analyses, both small and large space companies in the field of IOS are closely monitoring the evolutions and discussions related to MEV before making strategic decisions or starting activities in the field of IOS.[25] In addition, this success, as it is already the case for Northrop Grumman, can lead to additional contracts with both private and public actors. As a result, commercial success might trigger long-term contracts, improve trust among actors and creates a virtuous circle.

While the most advanced companies in the field of IOS are institutional actors and established space companies, there is an increasing number of start-ups trying to develop technologies for in-orbit services, in-orbit assembly and in-orbit manufacturing. However, the majority of these new ventures are still at the conceptual level.

## 2.3 Current Developments

### 2.3.1 Projects Overview

There are several in-orbit servicing projects and missions currently under development or announced by industrial or institutional actors. While the list is not exhaustive, it provides an overview of the variety of initiatives as well as the increasing number of private ventures in this domain.

Three types of funding are identified in the table below:

- Public: the programme or mission is funded by institutional actors such as space agencies or other governmental entities and/or public companies.
- Private: the programme or mission is funded by private companies, single individuals or venture capital.
- Public and Private: the programme or mission is funded by a combination of public and private funds.

The status provides an indicated level of maturity of the current or planned projects:

- Announced: the programme or mission was presented by the company or institution.
- Scheduled: the programme or mission is planned to launch at a specific date.
- Operational: the system or servicer is currently in orbit and working.
- Completed: the programme or mission was successfully launched and is now over.
- Uncertain: the programme or mission was not officially cancelled but it is unclear if the project is still under development or on hold.
- Cancelled.

| Main actor | Scheduled first launch | Project Name | Project Objective | Orbit | Funding | Status |
|---|---|---|---|---|---|---|
| NASA | 2018 | RRM3 | Refuelling | | | Completed |

[25] Corbin, B. and et al, 2020. Global Trends In On Orbit Servicing, Assembly And Manufacturing (OSAM). [online] IDA. Available at: <https://www.ida.org/-/media/feature/publications/g/gl/global-trends-in-on-orbit-servicing-assembly-and-manufacturing-osam/d-13161.ashx> [Accessed 27 November 2020].

| | | | | | | |
|---|---|---|---|---|---|---|
| SpaceLogistic (Northrop Grumman) | 2019 | MEV-1 | Life extension | GEO | Private | Operational |
| SpaceLogistic (Northrop Grumman) | 2020 | MEV-2 | Life extension | GEO | Private | Operational (rendezvous expected in 2021) |
| Effective Space Solutions, Astroscale Israel | 2020 | Space Drone 1 | Life extension | GEO | Private | Uncertain |
| Effective Space Solutions, Astroscale Israel | 2020 | Space Drone 2 | Life extension | GEO | Private | Uncertain |
| Astroscale | 2021 | ELSA-d | Active Debris Removal | LEO | Public/Private | Scheduled |
| OrbitFab | 2021 | Tanker-001 Tenzing | Refuelling | GEO | Public | Scheduled |
| NASA | 2021 | On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) | Refuelling and relocation | LEO | Public | Scheduled |
| NASA | 2022 | OSAM-2 | In-orbit manufacturing (3D printing) | | Public | Announced |
| NASA | 2022 | Lunar Orbital Platform Gateway | In-orbit Assembly | Cislunar | Public | Announced |
| Space Machines Company | 2022 | OT-S | In-Space Manufacturing, In-Space Logistics | LEO | | Announced |
| DARPA | 2023 | RSGS – Robotic Servicing of Geosyncronous Satellite | Repairs, augmentation, assembly, inspection, relocation | GEO | Public/Private | Announced |

| | | | | | | |
|---|---|---|---|---|---|---|
| ESA | 2025 | e.Deorbit | Multipurpose IOS | LEO | Public | Announced |
| ESA | 2025 | ClearSpace-1 (ADRIOS) | Active Debris Removal | LEO | Public | Scheduled |
| ESA/Thales Alenia Space | 2027 | ESPRIT, European Systems Providing Refuelling Infrastructure and Telecommunications (ERM) | Refuelling | Cislunar | Public | Announced |
| Roscosmos | 2030 | Nucleon | Refuelling and in-orbit assembly | Deep Space (Moon, Venus, Jupiter) | Public | Announced |

*Table 1: In-Orbit Services projects*

At the moment, it seems that the majority of IOS missions are still launched or funded by public actors. Most European start-ups which are involved in IOS missions and have scheduled a launch in the coming months or years are mostly funded publicly. Life extension, refuelling and active debris removal seem to be the most advanced and promising applications with several missions scheduled to launch in the next couple of years.

## 2.4 Current national policies

In-orbit services, close proximity operations or space rendezvous do not seem to be a top priority in the EU and in EU Members States. Indeed, they are rarely highlighted in public policies, strategies or speeches and when they are, they are almost never seen as a priority or as an innovative technological breakthrough that should be the subject of sustained investments from both public and private actors. Some countries even see it as a potential issue because of its potential military applications.

### 2.4.1 Multisectoral national policies

While in-orbit services are often limited to one aspect (either economic, innovation or defence) in European countries, the United States, China and Russia's policies have larger scopes.

#### United States

Since the 1960s, in-orbit services have been developed in the United States with strong support from NASA and DARPA. While the United States does not have a dedicated policy for IOS, DARPA founded CONFERS (The Consortium for Execution of Rendezvous and Servicing Operations) which is an initiative working on the development of "*best practices from government and industry for rendezvous and proximity operations (RPO) and on-orbit satellite servicing (OOS) operations*".[26] Today, the United States is the world leader in this domain and autonomous in-orbit services are seen as a priority by NASA, enabling US space missions and benefiting US national security as well as the space economy.

Indeed, in-orbit services can advance the US exploration-related missions, including the Gateway and the Artemis Missions as well as Moon and Mars exploration at large. In orbit assembly and manufacturing as well as cargo delivery will be key for the Lunar Gateway.

The 2019 NASA Authorization Act requested a feasibility study on *"in-space robotic refueling, repair, or refurbishment capabilities to extend the useful life of telescopes and other science missions that are operational or in development as of the date of the enactment of this Act."*[27]

Moreover, the policy of the United States regarding in-orbit services is part of a broader strategy to ensure the resiliency of the US space infrastructure. Not only the United States is launching hundreds of small satellites in LEO to provide redundancy and easily replace satellites in case of attacks or interference, but it is also replacing ground stations with a more resilient system. In addition, the United States is also looking at enhancing the resiliency of its satellites through in-orbit servicing (inspection, maintenance, repair, etc).[28]

In this domain, the United States, have also initiated some kind of Public-Private Partnerships for the funding of technological developments undertaken by private companies seeking commercial markets.[29] In November 2020, NASA launched the On-Orbit Servicing, Assembly and Manufacturing (OSAM) National Initiative to foster information-sharing as well as the creation of partnerships between industry, government and academia for the development of IOS capabilities. The initiative will also work on identifying gaps in the development of IOS technologies where public actors could provide funding.[30]

### China

As it is the case for United States and Russia, the Chinese involvement into In-Orbit Servicing has a strong governmental component and interest, for broad security reasons and defence capabilities, given the dual-use nature of RPOs. China is developing projects and capabilities in servicing, assembly and manufacturing.

In 2016, China published a Space White Paper highlighting its objectives: *"It plans to build in-orbit servicing and maintenance systems for spacecraft and make in-orbit experiments on new theories, technologies and products by tapping various resources."*[31]

According to CSIS's Space Threat Assessment 2020, China has been conducting RPOs in orbit for over a decade and has recently upgraded its technological demonstrations related to robotic arms, capability

[26] CONFERS. n.d. CONFERS - On-Orbit Servicing. [online] Available at: <https://www.satelliteconfers.org/> [Accessed 27 November 2020].
[27] Congress, 116th Congress, 1st Session. 2019. NASA Authorization Act. [online] Available at: <https://www.politico.com/f/?id=0000016e-4aad-dc5b-a5fe-6aed82510000> [Accessed 27 November 2020].
[28] Strout, N., 2019. Who Will Be Able To Fix A Satellite For The Air Force In 2025?. [online] C4ISRNET. Available at: <https://www.c4isrnet.com/battlefield-tech/space/2019/10/29/who-will-be-able-to-fix-a-satellite-for-the-air-force-in-2025/> [Accessed 27 November 2020].
[29] Decourt, R., 2018. Services Aux Satellites En Orbite : L'europe A Besoin D'un Véhicule De Deuxième Génération. [online] Futura. Available at: <https://www.futura-sciences.com/sciences/actualites/service-orbite-services-satellites-orbite-europe-besoin-vehicule-deuxieme-generation-69921/> [Accessed 27 November 2020].
[30] Foust, J., 2020. New Initiative To Promote Satellite Servicing And In-Space Assembly Technologies - Spacenews. [online] SpaceNews. Available at: <https://spacenews.com/new-initiative-to-promote-satellite-servicing-and-in-space-assembly-technologies/> [Accessed 27 November 2020].
[31] The Information Office of the State Council of the People's Republic of China. 2016. China's Space Activities In 2016. [online] Available at: <http://www.scio.gov.cn/wz/Document/1537091/1537091.htm> [Accessed 27 November 2020].

also relevant for ADR, as well as refuelling purposes[32]. A particular attention has been devoted to the manoeuvres of the SJ-17 in GEO during 2019, which seems to have conducted several RPOs but only with other Chinese spacecraft[33].

Overall, China's interest into developing IOS capabilities is also associated to the potential role of in-orbit assembly for future deployment of the Tiangong space station. In terms of policy, multiple Chinese strategic documents include In-Orbit Servicing as a focus area and "core technology", significant also in terms of economic advantages and efficiency. The Chinese role and future developments for IOS are centered on the Chinese Aerospace Science and Technology Corporation (CASC), with involvement of the Chinese Academy of Science, other institutions within CASC and universities focused on R&D.

### Russia

There seems to be no policy specifically dedicated to in-orbit servicing in Russia. However, the Russian Federal Space Programme 2016-2025 mentions in-orbit assembly as a major goal. Indeed, Russia considers the possibility to retrieve the Russian components of the ISS after its planned dismantling in 2024 in order to build a Russian space station.[34]

According to a study conducted by IDA, Russia has already used technologies for in-orbit inspection, relocation, refuelling and recharging. It has demonstrated repair and assembly operations capabilities including replacing obsolete parts of a space system in orbit and is currently developing in-orbit manufacturing.[35]
In 2017, Russia tested a manoeuvring military inspector satellite that was released from the satellite Kosmos-2519, flew autonomously, changed orbit, conducted inspection and returned to Kosmos-2519. This system could be able to determine the functions of nearby satellites and be used as a weapon in case of conflict.[36] In July 2020, Russia conducted a test by releasing an object from its Kosmos 2543 satellite. While it has been reported as a potential in-orbit ASAT test, Russia maintains it is only an inspector satellite. Kosmos 2543 and Kosmos 2542 also conducted close proximity operations around US spy satellite 245 in 2019. Besides, the Russian satellite Luch-Olympe approached several foreign satellites in GEO between 2017 and 2019 for what seemed to be SIGINT operations.

Moreover, the Military Space Academy A.F. Mozhaisky is developing a "space gas station" that could be used to provide recharging services through power beaming.[37] This project could take the form of a small constellation of satellites that would accumulate solar energy and then provide it to another spacecraft through laser beam.[38]
RSC Energia is developing in-orbit manufacturing capabilities. According to Benjamin Corbin et al., RSC Energia and the Tomsk Polythechnic University created a 3D printer nanosatellite on Earth and plans to

[32] Harrison et al., Space Threat Assessment 2020, Center for Strategic and International Studies (CSIS)
[33] Aerospace Security, CSIS. 2020. Unusual Behavior In GEO: SJ-17. [online] Available at: <https://aerospace.csis.org/data/unusual-behavior-in-geo-sj-17/> [Accessed 27 November 2020].
[34] Roscosmos.ru. 2016. Основные Положения Федеральной Космической Программы 2016-2025. [online] Available at: <https://www.roscosmos.ru/22347/> [Accessed 27 November 2020].
[35] Corbin, B. and et al, 2020. Op cit.
[36] Вальченко, С., Сурков, Н., Рамм, А. and Сурков, Н., 2017. Россия Послала На Орбиту Инспектора. [online] Известия. Available at: <https://iz.ru/662230/sergei-valchenko-nikolai-surkov-aleksei-ramm/rossiia-poslala-na-orbitu-inspektora> [Accessed 27 November 2020].
[37] Литовкин, Д., 2019. Заправка В Космос: В России Создают Проект Подзарядки Спутников На Орбите. [online] Известия. Available at: <https://iz.ru/906509/dmitrii-litovkin/zapravka-v-kosmos-v-rossii-sozdaiut-proekt-podzariadki-sputnikov-na-orbite> [Accessed 27 November 2020].
[38] Литовкин, Д., 2020. В России Работают Над Созданием «Орбитальных Бензоколонок». [online] Независимая газета. Available at: <https://nvo.ng.ru/realty/2020-05-29/5_1094_satellites.html> [Accessed 27 November 2020].

produce them in space in the near future.[39] In addition, the Russian company 3D Bioprinting Solutions built a 3-D printer that was sent on board of the ISS in 2018.

As a result, Russia is taking advantage of the dual-use aspects of IOS technologies as they are both developed for civilian and defence-related purposes. Most initiatives are public or publicly funded and there seems to be no private initiatives related to IOS, which is representative of the Russian space sector in general. However, the development of in-orbit services could be subject to budget cuts in the next few years as the budget for the Russian Federal Space Programme 2016-2025 is being reduced by 150 billion roubles due to economic contraction (including COVID-19 and low prices for oil and gas reducing state revenues).[40]

The US, China and Russia are the most advanced countries with regard to IOS both in terms of technological development and demonstrations. They are developing capabilities on the whole spectrum of in-orbit operations (in-orbit services, in-orbit manufacturing and in-orbit assembly) for both civilian and military benefits.

### 2.4.2 National policies focused on defence and security

Policies strictly dedicated to in-orbit services are rare but some national space policies mention in-orbit services. While they might also be interested in the economic benefits of IOS, some national policies are mostly oriented towards defence and security aspects, such as but not limited to:

#### France

In 2019, France released its Space Defence Strategy, in which it acknowledged the increasing importance in-orbit services will have in the future due to the high number of objects in orbit and the need to remove debris. However, on the one hand, France's Space Defence Strategy mainly highlights the dual use aspect of this technology and the risks for the weaponization of outer space: *"Under cover of civilian objectives, States or private actors can thus openly finance potential anti-satellite technologies."*[41] On the other hand, France plans to put nanosatellites, equipped with cameras, in orbit around some of its military satellites in order for the nanosatellites to "patrol" and detect potential attacks or hostile approaches. [42] This project, named ARES, is supposed to enhance situational awareness as well as protection and action in space. These nanosatellites could potentially be equipped with "self-defence" tools. The French Space Commander, Gen. Michel Friedling, precised that these systems are developed to deter attacks on French satellites and respond to new in-orbit threats.[43]

In addition, it must be noted that a parliamentary report from 2019 highlighted the potential benefits of close proximity operations and in-orbit services for the needs of the French Armed Forces, namely highly manoeuvring systems for refuelling and orbit correction. The report recommended to support the investments of ESA in demonstrators for in-orbit services and advises the French Armed Forces to invest

[39] Corbin, B. and et al, 2020. Op cit.
[40] ТАСС. 2020. Федеральную Космическую Программу До 2025 Года Урезали На 150 Млрд Рублей. [online] Available at: <https://tass.ru/kosmos/9280803> [Accessed 27 November 2020].
[41] Ministère des Armées. 2019. Strategie Spatiale De Défense. [online] Available at: <https://www.defense.gouv.fr/actualites/articles/florence-parly-devoile-la-strategie-spatiale-francaise-de-defense> [Accessed 27 November 2020].
[42] Ministère des Armées. 2019. Op cit.
[43] Ferrara, J., 2020. Avis au nom de la commission de la défense nationale et des forces armées sur le projet de loi de finances pour 2021. Tome VI. Défense, Préparation et emploi des forces : Air. Assemblée Nationale. p.58

in its own demonstrator in order to test in-orbit services with purely military applications.[44] CNES is currently developing a demonstrator, called Yoda, which is planned to launch in 2023 in order to demonstrate the capacity to conduct operations in GEO. It will consist in two nanosatellites that will approve close proximity operations, calculate the dimensions of payloads, and will serve as a training for the Space Command's future in-orbit operations. If successful, this demonstrator could become a fully operational system by 2030.

However, a parliamentary report on the 2021 defence budget warned that the Castor programme, which is supposed to replace the Syracuse programme[45] by 2028, is losing momentum and seems more or less on stand-by. This programme is supposed to digitalise satellites in order to enable in-orbit reconfiguration. A lack of interest in this programme could lead French industries to lag behind in the domain of in-orbit services.[46]

Finally, it must be noted that CNES is involved in the development of IOS in the field of Active Debris Removal (OTV study, SpaceBlower project, DRYADE mission, etc), reconfiguration (CASTOR1), and de-orbiting (Innovative DEorbiting Aerobrake System).

As a result, French policies are mostly defence-oriented when it comes to in-orbit services. While there are significant developments underway, in-orbit services are not at the core priority of the new Space Defense strategy but could enhance other policy and technical priorities such as SSA capabilities.

### 2.4.3 National policies focused on economy and innovation

Some policies are more oriented on the economic benefits of in-orbit services such as but not limited to:

#### Germany

German space policies are oriented on innovation and industrial manufacturing with a strong focus on automation and robotics, including key enabling technologies for in-orbit services.[47] While there is no public policy dedicated to in-orbit services, according to Benjamin Corbin et al., Germany perceives in-orbit services as *"a natural extension of Germany's terrestrial robotic and manufacturing prowess"*.[48]

In 2010, the German Orbital Servicing Mission (DEOS) was initiated to develop and demonstrate in-orbit services such as maintenance and repair operations as well as refuelling.[49] However, it was eventually cancelled after the definition phase.[50] The same year, DLR initiated the iBOSS project which contributed to the development of building blocks for modular, reconfigurable and fully serviceable satellite and demonstrated in-orbit assembly.

As a result, Germany is mostly focusing on the development of IOS key enabling technologies and the potential economic and industrial benefits for its industries and SMEs but it is not launching an IOS mission at the moment.[51]

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[44] Becht, O., Trompille, S., 2020. Rapport d'information, Secteur spatial de défense, Assemblée Nationale, p.131-133
[45] The Syracuse Programme is a SATCOM programme which started in 1980 and enables all French military communications and comprise 3 different generations of satellites.
[46] Ferrara, J., 2020. Op cit.
[47] DLR. n.d. Raumfahrtmanagement - Raumfahrttechnologie Und Raumfahrtrobotik: Nationales Programm. [online] Available at: <https://www.dlr.de/rd/desktopdefault.aspx/tabid-8289/14200_read-35920/> [Accessed 27 November 2020].
[48] Corbin, B. and et al, 2020. Op cit.
[49] DLR. n.d. Op cit.
[50] Gunter's Space Page. 2019. DEOS. [online] Available at: <https://space.skyrocket.de/doc_sdat/deos.htm> [Accessed 27 November 2020].
[51] Corbin, B. and et al, 2020. Op cit. p.5

### Italy

Among the current policy developments, Italy has recently highlighted the relevance of In-Orbit Servicing in the "Government Guidelines on Space and Aerospace"[52]. The guidelines are the first document related to space signed by the Prime Minister and the first high-level strategic document released after the reform of the Italian space governance. Published in March 2019, the guidelines identify IOS as a domestic strategic sector and possibly a new frontier in the development of future space activities. The document emphasizes the role of IOS mostly from the perspective of economic opportunities.

The "National Security Strategy for Space", released by the Prime Minister's office in July 2019, also includes a reference to IOS[53]. The strategy highlights the development of IOS capabilities from the perspective of the security of space environment. Specifically, as "the growing number of objects in orbit makes space an operating environment increasingly at risk of natural and accidental events, in addition to intentional threats", the government believes that is strategically important to develop SSA capabilities and support both STM and the emergence of IOS technologies.

Furthermore, the "Strategic Plan for Space Economy" prepared by the Presidency of Council of Ministers already in 2015 contains references to In-Orbit Servicing as a key technology; the plan goes further, considering IOS as enabler of future exploration activities, and stresses the need of financing innovative projects. Indeed, the Ministry has then allocated funds to start developments of IOS projects, as it is going to be discussed in following section on business challenges.

Building on the government Guidelines, the Italian Space Agency (ASI) focuses on IOS technology in the most recent strategic document (the DVSS 2020-2029[54]), as well as in the programmatic plan of activities[55]. From a policy standpoint, ASI reiterates the conclusions of the guidelines and identify In-Orbit servicing as one of the most significant developments for the overall space sector, as a technology capable of influencing several aspects of the space domain. From the DVSS, it seems clear that IOS is relevant for the development of national capabilities – allowing the country to position itself on the global sector – for the ability to provide competitive services, but also for a wider strategic significance that takes into consideration industrial as well as regulatory interests.

The identification of IOS as strategic interest from both economic and security perspectives has brought the Italian institutions to allocate funds for specific projects, which will be analysed more in detail in the section on business. Overall, the government and ASI proceed together to define a larger interest in IOS, to leverage existing and developing capabilities and strategic positions.

### UK

The UK government does not mention in-orbit servicing explicitly in its national space legislation, notably the Space Industry Act 2018. Nor does it have specific policies to promote in-orbit servicing. However, it is pursuing a number of initiatives to further the industry.

[52] Presidenza.governo.it. 2019. [online] Available at: <http://presidenza.governo.it/AmministrazioneTrasparente/Organizzazione/ArticolazioneUffici/UfficiDirettaPresidente/UfficiDiretta_CONTE/COMINT/DEL_20190325_aerospazio-EN.pdf> [Accessed 26 November 2020].
[53] Presidenza.governo.it. 2019. [online] Available at: <http://presidenza.governo.it/AmministrazioneTrasparente/Organizzazione/ArticolazioneUffici/UfficiDirettaPresidente/UfficiDiretta_CONTE/COMINT/DEL_20190325_aerospazio-EN.pdf> [Accessed 26 November 2020].
[54] Asi.it. 2020. [online] Available at: <https://www.asi.it/wp-content/uploads/2020/04/DVSS-2020-2022-Finale_compressed_compressed.pdf> [Accessed 26 November 2020].
[55] Asi.it. 2020. [online] Available at: <https://www.asi.it/wp-content/uploads/2020/04/DVSS-2020-2022-Finale_compressed_compressed.pdf> [Accessed 26 November 2020].

The UK has developed key technologies involved specifically in ADR. The RemoveDEBRIS mission was led by the Surrey Space Centre and launched in 2018.[56] The harpoon system used in the demonstration mission was developed by Airbus in Stevenage, UK, and other components from other UK based companies. The UK is also involved currently involved in the Clearspace-1 mission[57] and funding other space debris mitigation initiatives.[58]

In addition, the government is aiming to facilitate the development of new space technologies, including by creating infrastructure such as the National In-Orbit Servicing Control Centre.[59] This operational centre was funded with a £4 million government grant in partnership with Astroscale. It is operated in the Satellite Applications Catapult, a non-profit aiming to boost the UK industry and will be used by Astroscale for their first mission, ELSA-d. It will also be available to other operators.

Notable is the decision by Effective Space, a satellite servicing start-up founded in 2015, to locate their headquarters in London, despite most development and manufacturing occurring in Israel. There are likely a number of factors involved in this decision, but the UK space regulatory environment is receptive to new missions and this could have played a part. Whilst Effective Space was acquired by Astroscale in 2020, Infinite Orbits, another satellite servicing start-up, is also partially based in the UK.

### Luxembourg

Luxembourg's policies are business-driven and oriented on the exploitation and use of space resources with the goal to make the Grand Duchy a hub for commercial space activities.

Luxembourg's focus on space resources also aims to create opportunities in the field of in-orbit operations, in particular in in-orbit manufacturing and additive manufacturing as outlined in many documents such as the 2017 Report on Luxembourg Space Capabilities.[60] In 2020, Luxembourg partnered with ESA to create a European Space Resources Innovation Centre (ESRIC) to foster developments in space exploration and in-situ resource utilization (ISRU), which might boost IOS developments.[61]

Indeed, according to Benjamin Corbin et al., Luxembourg's policies allowing private companies to get property rights on the space resources they extract[62] is attracting foreign in-orbit manufacturing businesses and investments.[63] In addition, many Luxembourg companies such as Saturne Technology, e-Xstream, Kleos, Made In Space or Space Cargo Unlimited are currently developing in-orbit manufacturing.[64] **As a result, Luxembourg opted for a niche strategy and is now seen as a leader in the field of in-orbit manufacturing.**

[56] Surrey.ac.uk. 2020. Removedebris Mission | University Of Surrey. [online] Available at: <https://www.surrey.ac.uk/surrey-space-centre/missions/removedebris> [Accessed 27 November 2020].
[57] GOV.UK. 2020. UK To Play Critical Role In Building 'The Claw' - The First Ever Satellite To Remove Space Junk. [online] Available at: <https://www.gov.uk/government/news/uk-to-play-critical-role-in-building-the-claw-the-first-ever-satellite-to-remove-space-junk> [Accessed 27 November 2020].
[58] GOV.UK. 2020. Government Backs UK Companies Tackling Dangerous 'Space Junk'. [online] Available at: <https://www.gov.uk/government/news/government-backs-uk-companies-tackling-dangerous-space-junk> [Accessed 27 November 2020].
[59] UK Research and Innovation, 2020. In Orbit Servicing Control Centre, National Facility. [online] Gtr.ukri.org. Available at: <https://gtr.ukri.org/projects?ref=104193#/tabOverview> [Accessed 27 November 2020].
[60] Luxembourg Space Capabilities, Turning innovation into business 2017
[61] https://gouvernement.lu/en/actualites/toutes_actualites/communiques/2020/11-novembre/18-luxembourg-spaceresources.html ; https://space-agency.public.lu/en/news-media/news/2019/space-resources-innovation-centre.html
[62] http://legilux.public.lu/eli/etat/leg/loi/2017/07/20/a674/jo
[63] Corbin, B. and et al, 2020. Op Cit
[64] Space Directory 2020

### Japan

Japan does not have a policy dedicated to in-orbit services but some public policies mention IOS. Indeed, in 2014, the Committee on National Space Policy (CAO) released a vision document in which in-orbit services are considered as key activities for Japan to develop by 2040.

In addition, the Japanese space strategy identifies the development of in-orbit services, among other things, as a way to support Japanese New Space businesses and facilitate new entrants in the market.[65] In 2018, JAXA launched J-SPARC, a research and development programme dedicated to support the private sector. This programme supports activities related to extended stay in space as well as in-orbit services.[66]

Besides, in 2020, JAXA published safety standards for IOS missions in order to promote safe in-orbit operations, prevent collisions related to IOS, ensure interoperability between the servicing and serviced systems as well as quality assurance and liability provision for IOS.[67]

In 2013, the Japanese company Astroscale was founded and specialises in Active Debris Removal. This company managed to raise $191 million in funds, making it the most funded IOS company in the world.[68] In November 2020, Astroscale announced that it will launch the first commercial ADR mission named ELSA-D (End of Life Services by Astroscale-demonstration) in March 2021 on a Soyuz rocket from Baikonur, Kazakhstan.[69] Astroscale has also been involved in the field of life extension since it acquired the intellectual property of the Space Drone of the Israeli company Effective Space Solutions in 2020.[70] Additionally, the company is developing a satellite for in-orbit inspections with JAXA that would be used to inspect debris (mostly rocket upper stage) prior to ADR missions.[71]

As a result, Japan's initiatives in the field of IOS are mostly oriented towards space sustainability as well as economic benefits. Activities are supported by both public and private actors.

### India

India does not have a specific focus on In-Orbit Servicing at the national policy level. The draft of the new space policy, open for consultation between October and November 2020, does not provide new insights on the national involvement in the IOS area. However, over the last years ISRO has developed a project for testing RPOs and docking in orbit, to potentially expand its IOS capabilities but especially for the future evolvement of exploration mission involving also human participation. The Space Docking Experiment (SPADEX) is a mission originally scheduled for 2020 focused on attempting the docking between a chaser and a target spacecraft, to further demonstrate also control and separation phases and intended as a "fore-runner" for planetary missions.

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[65] ESPI Report Securing Japan
[66] ESPI Report Securing Japan
[67] JAXA. 2020. Safety Standards For On-Orbit Servicing Missions. [online] Available at: <https://sma.jaxa.jp/en/TechDoc/Docs/E_JAXA-JERG-2-026.pdf> [Accessed 27 November 2020].
[68] Sheetz, M., 2020. Astroscale, Which Fixes And Extends The Life Of Satellites In Orbit, Raises $51 Million. [online] CNBC. Available at: <https://www.cnbc.com/2020/10/13/astroscale-raises-51-million-to-expand-satellite-and-debris-services-.html> [Accessed 27 November 2020].
[69] Werner, D., 2020. Astroscale Announces 2021 Soyuz Launch Of ELSA-D Mission - Spacenews. [online] SpaceNews. Available at: <https://spacenews.com/astroscale-elsa-d-launch-2021/> [Accessed 27 November 2020].
[70] Erwin, S., 2020. Astroscale Moving Into GEO Satellite Servicing Market - Spacenews. [online] SpaceNews. Available at: <https://spacenews.com/astroscale-moving-into-geo-satellite-servicing-market/> [Accessed 27 November 2020].
[71] Henry, C., 2020. Astroscale Wins First Half Of JAXA Debris-Removal Mission - Spacenews. [online] SpaceNews. Available at: <https://spacenews.com/astroscale-wins-first-half-of-jaxa-debris-removal-mission/> [Accessed 27 November 2020].

### Summary

Overall, it should be noted that most countries do not have a policy dedicated to in-orbit services. However, it does not prevent them from developing projects, missions and capabilities in this field with different priorities.

On the one hand, some countries are interested in the economic benefits of IOS as a way to support the development of high added value technologies, support their industrial base, attract foreign investments and boost employment and growth. As a result, these countries might attract commercial demand for IOS more easily.

On the other hand, while some countries such as the United States, Russia, China or France are interested in the economic aspects as well, they are also focused on the military benefits of IOS and might attract institutional demand for IOS more easily.

In addition, it must be noted that some countries opted for niche strategies such as Luxembourg with in-orbit manufacturing or Japan with Active Debris Removal. As a result, these states are now leaders in their respective fields.

Finally, space sustainability seems to be a driver for the development of IOS regardless of the priorities of the countries.

## 2.5 Current European policies

There is no EU policy strictly dedicated to in-orbit services, but some key EU policies and strategies briefly mention IOS:

The Space Strategy for Europe explicitly mentions in-orbit services, but this technology is not a core priority for the EU. It mainly outlines that the Commission will support R&D needs in the field of in-orbit services and support in-orbit demonstrations.[72] This support for research and innovation is currently observed through the PERASPERA and the EROSS project.

Indeed, as part of the Horizon 2020 Programme, the EU developed the PERASPERA project which aimed at developing a roadmap of activities for a Strategic Research Cluster in Space Robotics Technology. The main objective is to develop a framework to develop the key enabling technologies for in-orbit services as well as planetary exploration by 2023/2024. This project is coordinated by ESA and includes France (CNES), Germany (DLR), Spain (CDTI), Italy (ASI), the United Kingdom (UKSA), Poland (PAK).[73] As part of this project, an assessment of European capacities for in-orbit services was conducted and concluded that IOS will require technologies with a higher level of maturity than state-of-the-art technologies, particularly in the field of data processing for in-orbit robotic operations as well as appropriate sensors for space rendezvous, inspection and capture. The report also concluded that modular manipulators and end-effector elements should be developed and that satellites should be designed to be serviced. [74] It seems that PERASPERA is collaborating with CONFERS on the development of standards for IOS.[75]

Furthermore, EROSS (European Robotic Orbital Support Services), another Horizon 2020 project, aims at developing in-orbit services capabilities such as space rendezvous, capturing, grasping, berthing and

[72] European Commission. 2016. Space Strategy For Europe. [online] Available at: <https://ec.europa.eu/docsroom/documents/19442> [Accessed 27 November 2020].
[73] European Commission. 2020. PERASPERA (AD ASTRA) Plan European Roadmap And Activities For Space Exploitation Of Robotics And Autonomy. [online] Available at: <https://cordis.europa.eu/project/id/640026> [Accessed 27 November 2020].
[74] EU, Orbital Studies,
[75] Corbin, B. and et al, 2020. Op Cit

manipulating a serviceable spacecraft in order to demonstrate in-orbit refuelling and payload replacement.[76] This project is improving the building blocks of the PERASPERA project and EU/ESA capabilities. EROSS also seems to be a reaction to NASA's developments and policies regarding in-space robotics. Indeed, the official EROSS website explicitly mentions NASA's 2015 technology roadmap in which autonomous rendezvous and docking as well as sensing and perception are identified as priority subsectors and the need for Europe to develop robotic spacecrafts and autonomous in-space capabilities to remain competitive.[77]

Besides, the European Commission also funded the project ADR1EN (First European System for Active Debris Removal with Nets) which aimed at continuing the development of a net for debris removal that was developed by the companies STAM, SKA and OptiNav through an ESA contract and reached TRL6. The objective was to push the technology to TRL7 by the end of the project with and develop a business and commercialisation plan for these three companies.[78]

The European Commission also funded the RemoveDEBRIS project which was coordinated by the University of Surrey (UK) between 2013 and 2019 and aimed at demonstrating key technologies for Active Debris Removal such as nets and harpoons to capture debris, electric propulsion and drag augmentation for de-orbiting missions as well as vision-based navigation for close proximity operations and rendezvous.[79]

Finally, the proposal establishing the space programme of the Union and the European Union Agency for the Space Programme mainly considers in-orbit services in the context of debris mitigation and the development of Space Surveillance and Tracking: *"with a view to reducing risks of collision, the SST would also seek synergies with initiatives of active removal and passivation measures of space debris."* While in-orbit services are not explicitly mentioned, the proposal outlines that the risk of collision should be assessed prior to in-orbit operations: *"SST shall comprise the risk assessment of collision between spacecraft or between spacecraft and space debris and the potential generation of collision avoidance alerts during the phases of launch, early orbit, orbit raising, in-orbit operations and disposal phases of spacecraft missions"*.[80] As a result, SSA and STM developments as well as the need to tackle debris might be a driver or a precursor for the development of IOS in the EU.

European policies and initiatives regarding in-orbit services are mostly focused on promoting European industrial developments as well as ensuring space sustainability.

## 2.6 ESA's role: a facilitator for developing in-orbit services

ESA has been studying the emergence of IOS for a long time since it conducted a study in 2007 on remote maintenance for communication satellites in GEO. This study called Satellite Servicing Building Blocks (SSBB) aimed at identifying the building blocks for IOS as well as their feasibility and profitability. The

[76] EROSS. 2020. Home - EROSS European Robotic Orbital Support Services. [online] Available at: <https://eross-h2020.eu> [Accessed 27 November 2020].
[77] EROSS. 2020. About Us - Application Context And Needs. [online] Available at: <https://eross-h2020.eu/about-us/strategic-research-cluster> [Accessed 27 November 2020].
[78] European Commission. 2020. First European System For Active Debris Removal With Nets. [online] Available at: <https://cordis.europa.eu/project/id/666758> [Accessed 27 November 2020].
[79] European Commission. 2020. A Low Cost Active Debris Removal Demonstration Mission - Removedebris. [online] Available at: <https://cordis.europa.eu/project/id/607099> [Accessed 27 November 2020].
[80] European Commission, 2018. EUR-Lex - 52018PC0447 - EN - EUR-Lex. [online] Eur-lex.europa.eu. Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2018:447:FIN> [Accessed 27 November 2020].

study resulted in the development of a gripper that was tested in a laboratory.[81] In 2013, ESA also announced the e.Deorbit program which was initially meant to lead to the de-orbiting of Envisat but the program was rescoped in 2018 to include several IOS functions such as refuelling.[82]

At the moment, ESA's initiatives with regards to in-orbit services are mostly oriented towards space sustainability and particularly Active Debris Removal. ESA's vision regarding IOS seems to be divided in 3 steps with the aim to support and develop ADR, transportation and inspection by 2025 (1), then to focus on refuelling and assembly by 2030 (2), to then take initiatives in the field of refurbishment, recycling and manufacturing after 2030 (3).[83]

Indeed, at the SPACE19+ Ministerial Council, ESA identified Active Debris Removal as a strategic goal and many projects in the field of ADR are being developed. The same year, ESA announced the launch of the e.Inspector project which aims to assess the feasibility of an in-orbit inspection mission to gather data about ENVISAT and investigate different system scenarios, assess programmatics, risk and core aspects of the design options and consolidate the technology road map in line with the programmatic aspects of the mission. The objective of the mission was to image ENVISAT and use the images to provide additional data prior to the e.Deorbit mission.[84]

In 2019, ESA also announced its first ADR programme called ADRIOS which aims at removing the VESPA upper stage by 2025. For this, ESA commissioned the Swiss-based company ClearSpace, which will launch ClearSpace-1 in 2025 to perform this mission. This project is presented by ESA as a service to *"help establish a new market for IOS"*. [85] ADRIOS also aims at demonstrating the feasibility of IOS key enabling technologies, provide a business model for IOS beyond the service provided by ESA and comply to space debris mitigation requirement.[86]

ESA is already working on the second and third step of its IOS vision and conduct prospective studies. In 2019, ESA conducted a study called OMAR (On-orbit Manufacturing Assembly and Recycling) which concluded that in-orbit recycling was not technically feasible with today's technologies and advised to focus more on refurbishment and manufacturing at the moment.[87] Also, in September 2020, ESA released an invitation to tender to study the potential for electrostatic discharge during IOS. The goal is to study several refuelling scenarios as well as the consequences of discharging.[88]

As a result, ESA is supporting the development and commercialisation of IOS by funding projects that enable private companies, either start-ups or established space companies, to demonstrate their technologies and accelerate their entry to market. According to a study conducted by the IDA, ESA has a role to play in the establishment of standards and policies regarding IOS but also to assist companies developing IOS.[89] In 2018, ESA's working group released a technical document on Guidelines for Safe Rendezvous and Capture for Commercial Missions which was then presented to CONFERS.[90]

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[81] Heemskerk Innovative Technology. 2008. Satellite Servicing Building Blocks (SSBB) · Heemskerk Innovative Technology. [online] Available at: <https://heemskerk-innovative.nl/projects/satellite-servicing-building-blocks-ssbb> [Accessed 27 November 2020].
[82] Henry, C., 2020. European Space Agency Overhauls Satellite Servicer Program - Spacenews. [online] SpaceNews. Available at: <https://spacenews.com/european-space-agency-overhauls-satellite-servicer-program/> [Accessed 27 November 2020].
[83] https://esamultimedia.esa.int/docs/Clean_Space/Webinar_OOSandADR_7May2020.pdf
[84] https://indico.esa.int/event/181/contributions/1378/attachments/1305/1530/e.Inspector_SARA.pdf
[85] https://www.esa.int/Safety_Security/Clean_Space/ESA_commissions_world_s_first_space_debris_removal
[86] ESA, 2020. In-Orbit Servicing And Active Debris Removal At ESA Webinar. [online] Available at: <https://esamultimedia.esa.int/docs/Clean_Space/Webinar_OOSandADR_7May2020.pdf> [Accessed 27 November 2020].
[87] https://blogs.esa.int/cleanspace/2019/09/09/esa-is-looking-into-futuristic-in-orbit-services-recycling-satellites/
[88] https://blogs.esa.int/cleanspace/2020/09/04/electrostatic-discharge-characterization-for-in-orbit-servicing/
[89] Corbin, B. and et al, 2020. Op cit.
[90] ESA. 2020. WEBINAR In-Orbit Servicing And Active Debris Removal At ESA. [online] Available at: <https://esamultimedia.esa.int/docs/Clean_Space/Webinar_OOSandADR_7May2020.pdf> [Accessed 27 November 2020].

# 3 CHALLENGES

## 3.1 Technical and technological challenges

According to recent reports, in-orbit services have not reached the highest level of technological readiness despite many tests and demonstrations. Indeed, in 2019, Joshua Davis et al. from Aerospace Corporation mentioned that *"with some exceptions, the ability to physically upgrade, refuel, or repair satellites once they are on orbit does not currently exist. "*[91] In 2020, NSR highlighted that *"In-orbit services have been constrained to low TRL due to lack of (enough) in-orbit demonstrations and thus a lack of confidence amongst customers."*[92] In 2020, Guglielmo Aglietti from the University of Auckland outlined in an article about the current challenges for space technologies that *"some progress has been made and some devices tested in-orbit, but we are still far from a real capability to perform Active Debris Removal or in-orbit servicing with sufficient confidence and at an affordable price."*[93]

It must be noted that among different agencies, TRLs are analysed from different viewpoints. While ESA and NASA often assign the highest TRL when the system was "flight proven" through successful mission operations[94], other institutions such as the European Commission prioritize the competitive commercialisation, manufacturing and availability of the technology for consumers in addition to the successful missions.[95]

[91] Davis, J., Mayberry, J. and Penn, J., 2020. On-Orbit Servicing: Inspection, Repair, Refuel, Upgrade, And Assembly Of Satellites In Space. [online] Aerospace.org. Available at: <https://aerospace.org/sites/default/files/2019-05/Davis-Mayberry-Penn_OOS_04242019.pdf> [Accessed 27 November 2020].
[92] NSR. 2020. In-Orbit Servicing: Technology And Market Readiness Undocked - NSR. [online] Available at: <https://www.nsr.com/in-orbit-servicing-technology-and-market-readiness-undocked/> [Accessed 27 November 2020].
[93] Aglietti, G., 2020. Current Challenges And Opportunities For Space Technologies. [online] Available at: <https://www.frontiersin.org/articles/10.3389/frspt.2020.00001/full> [Accessed 27 November 2020].
[94] NASA, 2020. Technology Readiness Level. [online] NASA. Available at: <https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html> [Accessed 27 November 2020].
[95] European Commission, 2020. Technology Readiness Levels (TRL). [online] Available at: <https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf> [Accessed 27 November 2020].

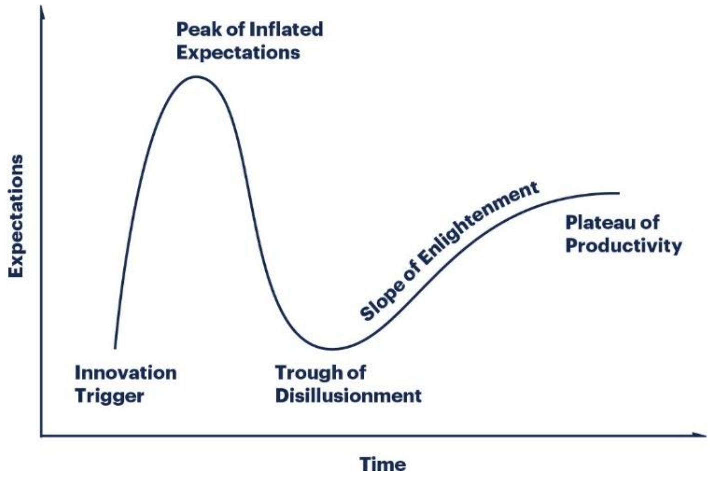
| | |
|---|---|
| TRL0 | **Idea:** Unproven concept, no testing performed yet |
| TRL1 | **Basic Research**: basic principles observed |
| TRL2 | **Technology formulation:** concept, technology and application formulated |
| TRL3 | **Proof of Concept:** Applied research to prove feasibility, first experiments in laboratory |
| TRL4 | **Prototype Development:** Functional verification in laboratory environment |
| TRL5 | **Breadboards verification in relevant environment** (small scale) |
| TRL6 | **Prototype demonstration** in a relevant environment (full scale) |
| TRL7 | **Prototype system demonstration in a space environment** |
| TRL8 | **Flight qualified**: successful test and demonstration in space |
| TRL9 | **Flight proven:** successful mission operations |

*Figure 3: Technological Readiness Levels*

In the aerospace sector, several authors and companies have identified the need to include two additional levels of technological readiness. Brown and McCleskey (2000) and Jeremy Straub (2015) have called for the creation of TRL10 to differentiate technologies that have been successfully tested in one mission from technologies that have been proven operational in the long-term and through multiple missions.[96] P.Lord et al (2019) also called for the creation of TRL10 which would be defined as "Reliable Flight Proven" and TRL11 as "Mature Flight Proven".[97] Besides, technology developers (creators) and applications developers (users) usually perceive TRLs differently by up to three levels.[98]

Moreover, emerging technologies can also be modelled using the Gartner Hype Cycle. It provides a graphic representation of the maturity and adoption of innovative technologies split up into five phases: innovation trigger (1), peak of inflated expectations (2), trough of disillusionment (3), slope of enlightenment (4) and plateau of productivity (5):

[96] K. Brown, C. McCleskey, National spaceport testbed, in: 1999 Space Congress, 2000;
[97] Straub, J., 2015. In search of technology readiness level (TRL) 10. Aerospace Science and Technology. 46. 10.1016/j.ast.2015.07.007.
[98] J. Robinson, at al, Need for technology maturity of any advanced capability to achieve better life cycle cost, in: 45th 99 AIAA/ASME/SAE/ASEE Joint Propulsion Conference, 2009.




*Graphic 1: Gartner Hype Cycle*[99]

The successful launch of the first fully commercial in-orbit servicing initiative in 2019 and its successful docking (MEV-1 with Intelsat-901) in 2020 increased the overall TRL of in-orbit services. As a result, technology cannot be considered as a major obstacle for life extension. It could be assessed that in-orbit services have now reached the 8th level of technological readiness.[100] Not only a significant number of in-orbit services have been demonstrated but they are also slowly becoming available to customers. According to NSR, in-orbit services are expected to reach the plateau of productivity by the end of the decade.[101]

When assessing the technological readiness level of in-orbit services, it is also important to consider the myriad of key disruptive technologies enabling in-orbit services as a whole. The rate of adoption of in-orbit services will likely be different depending on the use cases as well as the maturity of enabling technologies.[102]

Nonetheless, some in-orbit services are yet to be demonstrated, especially in the field of reconfiguration and in-orbit assembly. In addition, several technical and technological challenges remain in terms of autonomy (3.1.1), standardisation (3.1.2), mobility and manoeuvrability (3.1.3), Guidance, navigation and Control (3.1.4) and Active Debris Removal (3.1.5).

### 3.1.1 Autonomy

The degree of autonomy required for in-orbit servicing varies. Early rendezvous and docking procedures were flown by hand by astronauts on board the spacecraft. For uncrewed spacecraft, controlling the spacecraft entirely remotely is unlikely to be a workable solution, due to issues with downlinking data and latency. Instead, the spacecraft would conduct a series of manoeuvres autonomously, often prompted by commands from the ground, with checks in between each manoeuvre. For the rendezvous to be autonomous, authority approval points are needed.[103]

[99] Gartner. 2020. Hype Cycle Research Methodology. [online] Available at: <https://www.gartner.com/en/research/methodologies/gartner-hype-cycle> [Accessed 27 November 2020].
[100] NSR. 2020. In-Orbit Servicing: Technology And Market Readiness Undocked - NSR. [online] Available at: <https://www.nsr.com/in-orbit-servicing-technology-and-market-readiness-undocked/> [Accessed 27 November 2020].
[101] Ibid.
[102] Corbin, B. and et al, 2020. Op cit. p.9
[103] Reesman. R., 2018. Op cit. p.8

**Artificial intelligence for IOS: technological challenges at the intersection of SSA and IOS**

Artificial intelligence may play a part in solving the issue of space debris. In an active debris removal mission, the approaching satellite must rendezvous with and identify the target satellite. To identify the debris, visual cameras can be used. Identification is difficult due to the potentially rotating, shiny nature of the target satellite, which may not be in the same condition as it was launched. Deep learning algorithms, trained using data obtained on the ground, can be used to process the images from the cameras and assess the functionality and state of the satellite. This approach is being developed at EPFL in Switzerland for use in the ClearSpace mission. [104]

At the moment, Artificial Intelligence seems to be a useful tool to compile and analyse SSA data in order to facilitate space rendezvous and docking and avoid collisions or accidents during IOS missions. AI can also be used to secure data transfers and intersatellite communications during the servicing mission.

However, while AI provides some added value for IOS in terms of data processing and patterns recognition, it is unlikely that IOS operations become fully autonomous. According to the IDA, IOS, especially assembly and manufacturing will continue to require a *"human in the loop approach facilitated by in situ or teleoperations."*[105]

### 3.1.2 Standardisation

At the moment, most satellites in orbit are not designed to be serviced and tugged, which is an obstacle to the development, generalisation and commercialisation of in-orbit services. On top of that, the lack of standardisation among space systems creates an interoperability issue.[106] If some satellites are designed to be serviced, their systems might not be compatible with all space tugs or other IOS instruments. Standardisation enables to service and dock more systems but could also enable space tugs to provide multiple services during the course of one mission, thereby increasing the cost-effectiveness of IOS.

In the same way computers of any brand all have a USB port, standardisation would require most space systems to have an interoperable interface, docking or grapple fixture that the servicing spacecraft can grab or connect to.

Without some standardisation efforts and the creation of technical committees to ensure the interoperability of systems, components and software, in-orbit assembly and in-orbit services would not have been possible on the ISS.[107]

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[104] Petersen, T., 2020. Deep Learning Algorithms Helping To Clear Space Junk From Our Skies. [online] EPFL. Available at: <https://actu.epfl.ch/news/deep-learning-algorithms-helping-to-clear-space-ju/> [Accessed 27 November 2020]. /

[105] Boyd, I., et al. 2017. On-Orbit Manufacturing And Assembly Of Spacecraft. [online] Ida.org. Available at: <https://www.ida.org/-/media/feature/publications/o/on/on-orbit-manufacturing-and-assembly-of-spacecraft/on-orbit-manufacturing-and-assembly-of-spacecraft.ashx> [Accessed 27 November 2020].

[106] Promoting international co-operation in the age of global space governance – A study on on-orbit servicing operations

[107] Piskorz, D. and Jones, K., 2020. ON-ORBIT ASSEMBLY OF SPACE ASSETS: A PATH TO AFFORDABLE AND ADAPTABLE SPACE INFRASTRUCTURE. [online] The Aerospace Corporation. Available at: <https://aerospace.org/sites/default/files/2018-05/OnOrbitAssembly_0.pdf> [Accessed 27 November 2020].

- Standardisation from a mechanical perspective:

At the moment, most satellites in GEO can be grappled through their liquid apogee engines, which is the option that was retained by Northrop Grumman for the rendezvous between MEV-2 and Intelsat 10-02. The company highlighted that MEV was designed to grab various types of liquid apogee engines which led to the success of the mission. This confirms statements made in a recent NASA report which indicated that satellites that are not designed to be serviced do not constitute a major blocking point to the development and commercialisation of IOS.[108] However, Northrop Grumman also highlighted that satellites are increasingly using electric propulsion and do not have such fixture that space tugs can grab to provide services.[109]

From a business standpoint, standardisation is an advantage for private companies as it gives more flexibility to the supply chain and enables them to procure their components from several manufacturers. However, established companies in the field of grapple fixtures could have a significant advantage if the system they produce becomes a global standard. If a company has a dominant position, it could push others to adopt its standard. In such case, companies creating different or mission specific fixtures will have to pay additional efforts to adapt to the new standards. Therefore, there is an interest for both public and private actors to take part into consortia or initiatives (CONFERS, CCSDS, etc) working on standardisation and best practices in order to gain a lobbying power.

OneWeb's satellites orbit at an altitude of 1200 km, meaning they will not de-orbit naturally within 25 years (as recommended by the IADC) should the propulsion system fail. Thus, the satellites feature a grappling fixture to enable them to be deorbited by a future active debris removal service.

- Standardisation from a digital perspective:

IOS require some data transfers and communications between the servicer and the serviced satellite. Therefore, the two systems should have an interoperable interface for information exchange. This software and interface compatibility is even more important for in-orbit assembly as several systems will merge into one large infrastructure in which data and power have to be exchanged.[110]

However, standardisation can bring other types of risks related to the weaponization of outer space. Indeed, standardisation usually means that some components or parts of most IOS systems, interface or networks are more or less identical. From a digital perspective, it will make it easier for an attacker to buy COTS components that are widely present in IOS systems and look for vulnerabilities. If there is standardisation, finding vulnerabilities in one system usually means it might be present in other systems as well. Additionally, according to James Pavur from the University of Oxford, while standardisation is always a good thing to have, most international standards and protocols are publicly available and can provide an attacker with critical information about how a system works, which frequencies or software it uses, thereby lowering the barrier of entry to attack space systems.[111] This aspect was also highlighted by Danielle Piskorz and Karen Jones in a study conducted by the Aerospace Corporation: standardisation could be seen as strong driver for the development and commercialisation of IOS but institutional actors

[108] NASA Goddard Flight Centre, 2010. On-Orbit Satellite Servicing Study Project Report. [online] NASA. Available at: <https://nexis.gsfc.nasa.gov/images/NASA_Satellite%20Servicing_Project_Report_0511.pdf> [Accessed 27 November 2020].
[109] Foust, J., 2020. Satellite Servicing Industry Seeks Interface Standards - Spacenews. [online] SpaceNews. Available at: <https://spacenews.com/satellite-servicing-industry-seeks-interface-standards/> [Accessed 27 November 2020].

[111] Pavur, J., 2020. Space for the IoT: between the race for connectivity and cybersecurity concerns, Webinar, SGAC

might be more reluctant to pursue standardisation and consider it as a risk for the security of in-orbit operations that have military purposes.[112]

### 3.1.3 Mobility and Manoeuvrability

In-orbit services imply manoeuvres in already crowded and contested orbits in which it is not always clear why a system stops working. The biggest risk during an IOS mission is to collide with another spacecraft or debris while attaining the serviced spacecraft or damaging the servicer or the serviced system during the rendezvous and docking procedures. This seems to be perceived as a high risk by IOS operators, especially in this nascent business where a failure or accident can break the case for IOS. For instance, when Northrop Grumman launched the MEV, the company chose to first move the serviced satellite to a graveyard orbit in order to dock and service it in order to avoid collisions with an active satellite in GEO.[113]

However, the emergence of highly manoeuvrable systems such as the X37B which are presented as "Swiss knifes" capable of conducting close proximity operations, in-orbit inspections and may be equipped with robotic arms.[114] It remains to be investigated how this type of systems could be used for IOS and how they could improve the challenges related to manoeuvrability.

### 3.1.4 Guidance, navigation and control

Guidance, Navigation, and Control of the spacecraft (GNC) is a key enabler of autonomy. It includes how the spacecraft is able to localise its position and orientation and control itself to achieve its aim. It is an extension of the altitude and orbital control system (AOCS) of the satellite, and is particularly relevant for close proximity operations, where inaccurate GNC could cause the loss of two spacecraft and the creation of myriad space debris. It is also made more difficult in the case of active debris removal, where the target may be tumbling. In such case, the approaching spacecraft must match the rotation rate of the target before attempting to capture it.

Technology for GNC is similar to that being adopted for terrestrial autonomous systems such as autonomous cars and unmanned aerial vehicles, though the space environment presents distinct challenges for localisation. Specifically, GNC involves sensors make measurements in the local environment, and algorithms that can process this information and turn it into control commands. For close proximity operations, sensors beyond normal spacecraft sensors (star trackers, GPS etc.) include technology such as lidar, radar and visual cameras (for Vision Based Navigation, VBN). These sensors identify the position of the target satellite and therefore map the local environment. Algorithms interpret the data from these sensors to identify the target satellite and control the approaching satellite with thrusters and reaction wheels.

### 3.1.5 Active Debris Removal

Active debris removal involves the rendezvous and docking with, and ultimately removal of, an item of space debris. Debris is generally understood to be manmade non-operational space objects, including rocket upper stages, decommissioned satellites and fragments thereof caused by collisions and breakup

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[112] Piskorz, D. and Jones, K., 2020. ON-ORBIT ASSEMBLY OF SPACE ASSETS: A PATH TO AFFORDABLE AND ADAPTABLE SPACE INFRASTRUCTURE. [online] The Aerospace Corporation. Available at: <https://aerospace.org/sites/default/files/2018-05/OnOrbitAssembly_0.pdf> [Accessed 27 November 2020].
[113] Interactive.satellitetoday.com. n.d. The Time For On-Orbit Satellite Servicing Is Here. [online] Available at: <http://interactive.satellitetoday.com/the-time-for-on-orbit-satellite-servicing-is-here/> [Accessed 27 November 2020].
[114] Becht, O., Trompille, S., 2019. Op cit.

events. The largest pieces of space debris, in the most common orbit position in LEO, present a challenge for the long-term sustainability of space, and active debris removal could contribute to solve this problem. The primary technical challenge for active debris removal missions is the docking procedure. As space debris is non-functional, it is likely not to controllable from the ground, known as a non-compliant target. Furthermore, the debris could be tumbling, or rotating, and may have few ways of being captured and manipulated by the approaching satellite.

Several docking or capture mechanisms have been proposed and or tested.

### Mechanical

Mechanical solutions to grapple space objects have long been used, for example the Canadarm on the Space Shuttle and ISS. Simpler models such as 'tentacles' or claws have also been proposed. Mechanical manipulators are the most technically advanced solution to capturing space objects, involving advanced robotics and many moving parts. Mechanical solutions can be specialised to a single task, such as docking with a liquid apogee engine seen in the MEV-1 mission, or more general. However, increasing complexity increases the risk of failure and the cost of such a device. For the more delicate manipulation required in more advanced in orbit servicing, they are a requirement, but for simply capturing space debris, other solutions may be preferable, depending on the target.

### Magnets

Astroscale is using magnets in its demonstration mission ELSA-d. This requires fewer moving parts (and hence failure modes) and is likely to be cheaper than a mechanical mechanism. However, it requires a magnetic surface on the target satellite. Furthermore, the magnetic surface must be positioned in such a way that the approaching satellite can manipulate the two satellites once connected. It is possible with specially made magnetic docking points but these would have to be integrated into the design of the spacecraft before launch.

### Nets

Nets have been proposed as a way of capturing, in particular, non-cooperative debris. The capturing spacecraft would not to dock with the debris, and could capture from a distance. This technology was tested as part of the RemoveDEBRIS mission, where a target piece was ejected from the satellite, before being captured by the net. However, this has some downsides. The unpredictable capture of the satellite means it could be positioned in a way that makes manoeuvring once captured difficult. Furthermore, there is only one chance to capture the debris, and any failure could exacerbate the debris problem.[115] [116]

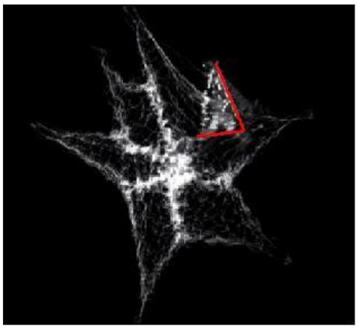


*Figure 1 RemoveDEBRIS net deployment, with the target satellite highlighted (Source: RemoveDEBRIS team)*

### Harpoons

Harpoons have been proposed as a mechanism for capturing space debris. Indeed, the RemoveDEBRIS mission tested a harpoon, firing it into

[115] Rinalducci, A. et al., 2020. Guidance, Navigation, And Control Techniques And Technologies For Active Debris Removal. [online] Available at: <http://iaassconference2013.space-safety.org/wp-content/uploads/sites/19/2013/06/1600_Ortega.pdf> [Accessed 27 November 2020].

[116] eoPortal Directory. 2020. Removedebris - Satellite Missions - Eoportal Directory. [online] Available at: <https://directory.eoportal.org/web/eoportal/satellite-missions/r/removedebris> [Accessed 27 November 2020].

a target 1.5 m away. Use of a harpoon, as with a net, means there is reduced risk from collision.[117] However, harpoons have significant risk. Only one attempt at capture can be made, there is a significant risk of creating more debris, and once captured the target may be difficult to manipulate.

#### Deorbit mechanisms

Once captured, the two spacecraft must move to a different orbit, either to allow the spacecraft to deorbit naturally through the Earth's atmosphere or to reach a graveyard orbit. This could be achieved with the propulsion system of the capturing spacecraft, but could also be enhanced through the use of drag sails or electrodynamic tethers.

Tethers involve releasing a length of material which then increases the drag experienced by the satellite, making it deorbit faster. A test of such a tether, conducted with a control satellite to compare the results, was launched in 2020.[118]

Furthermore, drag sails could be used to speed up deorbit. These involve increasing the cross-sectional area of the satellite to increase the drag. A drag sail was tested as part of the RemoveDEBRIS mission.

### 3.1.6 Key Enabling Technologies

For IOS to be operational, a number of key enabling technologies have to be developed. It must be noted that TRLs of these technologies was not identified as a major constraint for the development of in-orbit services in a quantitative study conducted by the IDA. However, regarding assembly and manufacturing, reaching high TRLs were seen as quite challenging.[119]

Here is a non-exhaustive list of enabling technologies and their usage:

| Name of the technology | Usage |
|---|---|
| Additive Manufacturing | In-orbit manufacturing |
| Advanced Robotic Arms | Advanced manipulation, e.g. manufacturing |
| Computer Vision | Sensing and identifying target satellite |
| Drag sails | Increasing drag for deorbit |
| Electromagnetic tethers | Increasing drag for deorbit |
| Fiducials | Markers to align docking mechanisms |
| Fine Control Propulsion | RPO and docking |

[117] ESA Blogs. 2019. COULD A HARPOON HELP CLEANING UP SPACE FROM DEBRIS?. [online] Available at: <https://blogs.esa.int/cleanspace/2019/07/31/could-a-harpoon-help-cleaning-up-space-from-debris/> [Accessed 27 November 2020].
[118] Erwin, S., 2020. Millennium Space Experiment To Measure Speed Of Satellite Deorbiting System - Spacenews. [online] SpaceNews. Available at: <https://spacenews.com/millennium-space-experiment-to-measure-speed-of-satellite-deorbiting-system/> [Accessed 27 November 2020].
[119] Carioscia, S., Corbin, B. and Lal, B., 2020. Roundtable Proceedings: Ways Forward For On-Orbit Servicing, Assembly, And Manufacturing (OSAM) Of Spacecraft. [online] Available at: <https://www.ida.org/-/media/feature/publications/r/ro/roundtable-proceedings-ways-forward-for-on-orbit-servicing/d-10445.ashx> [Accessed 27 November 2020].

| | |
|---|---|
| GNC | Sensing target satellite for docking |
| Lidar, Radar, visual cameras | Sensors for computer vision |
| Modular Payloads | Changing or replacing payloads |
| Power beaming | Transferring energy over long distances |
| Precision Manipulators | In-orbit assembly |
| Robotic Arms | Manipulating target satellite |
| Space welding | In-orbit manufacturing |
| Standard grappling interfaces | Increase docking capability |
| Standard interface | Transferring power and data |

*Table 2: Key enabling technologies for in-orbit operations*

According to a study from the Institute for Defense Analyses, most of these technologies are under development. Among in-orbit operations, in-orbit manufacturing seems to have the lower level of technological readiness. According to Iain Boyd et al, in-orbit manufacturing would require additional investments and technological development to reach a higher level of technological readiness, in particular regarding the raw materials that can be used for additive manufacturing, the technics that can be used to create components that cannot be produced by 3-D printing, the evaluation of material properties that can be manufactured in orbit as well as the development of procedures to augment the size of structures that can be built in orbit.[120]

In-orbit manufacturing is closely linked to space mining and the exploitation of space resources, which is still considered a futuristic business. As a result, the rate at which in-orbit manufacturing is being developed and adopted might be accelerated if major advancements are made in the field of space mining as some of the key enabling technologies are the same.

[120] Ibid.

## 3.2 Legal, political and military challenges

### 3.2.1 International space law

The emergence of in-orbit servicing presents a number of issues in regard to international law. Whilst none are severely threatening the services, they should be discussed and mitigated to ensure in orbit services can function most effectively. Some legal issues are wider than in-orbit services, whilst some are unique to commercial remote proximity operations.

The body of international space law comprises five international treaties and numerous soft law instruments. Most pertinent to in-orbit servicing are the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty) of 1967[121] and the Convention on International Liability for Damage Caused by Space Objects (Liability Convention) of 1972[122] .

Article VII states:

*Each State Party to the Treaty that launches or procures the launching of an object into outer space, including the moon and other celestial bodies, and each State Party from whose territory or facility an object is launched, is internationally liable for damage to another State Party to the Treaty or to its natural or juridical persons by such object or its component parts on the Earth, in air or in outer space, including the moon and other celestial bodies.*

Article IX states, inter alia:

*If a State Party to the Treaty has reason to believe that an activity or experiment planned by it or its nationals in outer space, including the moon and other celestial bodies, would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space, including the moon and other celestial bodies, it shall undertake appropriate international consultations before proceeding with any such activity or experiment.*

From these articles, two main points are relevant. The first is that states are liable for their actions in space. This means private organisations, when they conduct activities in space, are doing so under their state. The second is that states (and therefore organisations within states) cannot interfere with the actions of other states without appropriate international consultations. This means states cannot rendezvous and dock with other state's satellites without clear consultation beforehand, as one would expect. However, as debris can be attributed to states, it means states cannot clear debris without similar consultations.

The Liability Convention expands on the first point. Article III states:

*In the event of damage being caused elsewhere than on the surface of the earth to a space object of one launching State or to persons or property on board such a space object by a space object of another launching State, the latter shall be liable only if the damage is due to its fault or the fault of persons for whom it is responsible.*

[121] United Nations Office for Outer Space Affairs, *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space,* 1966.
[122] United Nations Office for Outer Space Affairs, *Convention on the International Liability for Damage Caused by Space Objects,* 1971.

However, the definition of fault is not clear across many potential scenarios, including in-orbit servicing. Ewan Wright (2020) highlights the issue of determining fault in the context of a in orbit servicing mission collision:

*Is the approaching satellite at fault, because it approached the target satellite, or is the target satellite at fault for being close to failure in the first place? Which satellite malfunctioned at the critical time, causing the collision? Did the satellites make contact before the breakup?*[123]

If a servicing satellite collides with a target satellite, or a piece of space debris, there are two consequences. First, it is not clear who is at fault, and caused the collision. Secondly, it is difficult to ascertain which piece of ensuing debris came from which spacecraft, especially in remote proximity operations with low relative velocities. This is relevant because the debris could go on to damage other spacecraft. Dividing a debris cloud between two states is unlikely to be a workable solution, so the state at fault could be held responsible for all of the ensuring debris.

It is important to note that this primarily concerns missions between states. Missions, such as MEV-1, conducted between two organisations intra state can occur without express permission from other states. However, the activities will still be bound by the body of space law. Despite this, the organisations will face similar about fault and liability, and details will have to be elaborated upon in the service contracts between organisations, and in discussions with appropriate national regulators. Whilst the details of the arrangement underpinning MEV-1 are commercially sensitive and not publicly available, the open development of norms and best practices will help the emergence of the market, including to start-ups which may not be as familiar with space activities as incumbent space companies. Regulators could develop clear liability regimes for all possible outcomes to ensure those offering and using in-orbit services are fully aware of potential risks and identify which organisation would be liable.

### 3.2.2 Active debris removal

In addition to the issues outlined above, active debris removal faces further issues due to the nature of space debris. Space debris is not defined in the space treaties, though the UN COPOUOS, in its Debris Mitigation Guidelines 2007, endorsed by the General Assembly, define space debris as:

*All man-made objects including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional.*[124]

Space debris, under a strict liability regime, is still a space object for which a state is liable, regardless of size, function, and formation. The issues associated with in-orbit servicing outlined above still apply, only the dynamic of space debris clearance is different to more commercial services. If the legal solutions around fault and liability are too strict, it could disparage efforts to reduce space debris, a goal beneficial for all space actors.

If other states wish to remove space debris from orbit, they must obtain approval from the owner state of the space debris. One potential mechanism to mitigate this, noted by Zhuang Tian and Yangyang Cui (2020), would be to transfer ownership of the space object to the same state as that which is retrieving it.

[123] Wright, E., 2020. Legal Aspects Relating to On-Orbit Servicing and Active Debris Removal. On-Orbit Servicing: Next Generation of Space Activities. Studies in Space Policy, ESPI, ch. 9. ISBN 978-3-030-51558-4.
[124] United Nations Office for Outer Space Affairs. 2010. Space Debris Mitigation Guidelines Of The Committee On The Peaceful Uses Of Outer Space. [online] Available at: <https://www.unoosa.org/pdf/publications/st_space_49E.pdf> [Accessed 27 November 2020].

All actors and states would of course have to agree to this, and some national space legislation allows for it.[125] However, transfer of ownership may be limited by export control regulations.

The continued tracking and identification of space debris objects, long after a breakup event, becomes difficult. Few states have space object tracking systems, with notably the United States having the most comprehensive tracking system under USSTRATCOM. Other states are therefore reliant on their interpretations. States causing breakups through in-orbit servicing, in a future collision for instance, could dispute their attributed ownership of a piece of debris. Better, and independent, tracking capabilities would help remove this uncertainty.

These issues, if they are not properly addressed ahead of missions, could cause significant international relations issues. The number of cases addressed under the body of space law is small, and states may be reticent to set precedent around these issues. However, they must be considered to ensure that in-orbit services are not overly hindered by legal issues.

**The INTELSAT Model: managing ADR and avoiding misinterpretations and escalating behaviours regarding proximity operations**

The International Interdisciplinary Space Debris Congress (3rd edition, 2012) and a later study from McGill University and IAASS (Jakhu, Nyampong, Sgobba, 2017) advocate for the creation of an institutional mechanism to ensure the sustainability of space and the feasibility of ADR. This mechanism would be based on the model of INTELSAT, the intergovernmental organization created in 1964 to operate and provide telecommunication services.

Given the several legal and technological challenges to the emergence of IOS/ADR capabilities and the urgency to take actions concerning space debris mitigation, the report finds in the original Intelsat model of an international organisation the way toward the – shared, sustainable and operational – adoption and commercialisation of space debris removal and servicing operations.

Proposedly called INREMSAT (International Debris Removal Satellite), the organisation so modelled would:

- put together more states and private entities to procure the “development, deployment and commercialisation of debris removal spacecraft”;
- facilitate the adoption of national legislation concerning space debris mitigation rules
- support the implementation of a national “space-garbage-collection” tax, associated with the process of obtaining the license to launch;
- INREMSAT could then potentially follow the same evolution of INTELSAT (eventually going private in 2001, after more 30 years from the establishment).

The INMERSAT proposal could be a solution to the mistrust concerning RPOs and would present a multilateral way to share the burden of an expensive and risky business, often referred to as an example of the “tragedy of commons”. The idea of imposing a “garbage-collection” tax to the final users in the space business would bring some revenues to the state, and member of the organisation participating in the endeavour of multiple ADR services, conferring also a sort of value to the sustainability of the space environment.

[125] Tian, Z. and Cui, Y., 2020. Legal Aspects of Space Recycling. On-Orbit Servicing: Next Generation of Space Activities. Studies in Space Policy, ESPI, ch.3. ISBN 978-3-030-51558-4.

### 3.2.3 Legal considerations for exportations

Export control regimes are particularly concerned with space technologies. In the United States, the strict export rules contained in the International Trafficking in Arms Regulations (ITAR) prevent export of many space technologies. Many other countries have similar regulations, with specific or *ad hoc* export controls on certain space components. For example, the German government recently blocked export of optical intersatellite links to China.[126] These rules have two primary consequences related to in-orbit servicing. In the manufacturing stage, they restrict the available supply chain for a manufacturer, limiting their choice of components. In orbit, the rules could prevent the transfer of ownership of spacecraft and debris that would reduce liability requirements under international law, as outlined in the previous section. Furthermore, countries would likely restrict the states allowed to approach and service their satellites for national security concerns. This presents some business opportunities, as addressable markets may vary based on the state of ownership of the company. For example, a Chinese company is unlikely to service a US satellite, so both US and Chinese companies must develop technology independently.

In case the United States accepts to sell IOS technologies that are under ITAR to another country for a specific usage, the user country would need the authorization of the United States to use it for other purposes. Additionally, if an IOS technology is developed by a European company and contains US components that are under ITAR, the country would need the authorization of the United States to export this technology. For example, in 2018 the sale of French Rafale fighter jets to Egypt was blocked by the US Department of state because the Scalp missiles used by the Rafale contained ITAR controlled components. As a result, this regulation can have a significant impact on European companies for the commercialisation and exportation of IOS at the international level.

### 3.2.4 Concerns regarding the weaponization of outer space

While states are forbidden to place weapons of mass destruction in orbit, the use of conventional ASAT weapons is legal under international law. As most space technologies, satellites capable of performing in-orbit servicing missions could also use their capabilities to nefariously damage or destroy satellites.

In theory, all satellites could be used as blunt weapons to collide with, and ultimately destroy, other satellites, though this would be difficult to achieve due to the constraints of typical satellite designs. However, servicing satellites have additional technical capability to rendezvous with and damage satellites. Robotic arms or harpoons for ADR could be used as a kinetic weapon to damage an adversary's satellite and servicing satellites could potentially be equipped with a directed-energy weapon (laser). Furthermore, it is theoretically possible that a servicing satellite could be hijacked by third-party organisations, who then use it nefariously.

Any such manoeuvre, from state or third party, without permission from the target satellite owner, would have several consequences. The more explicit dual use component of satellite servicing technologies makes them a national security concern, and if states develop such spacecraft in secret, international tension around the weaponization of outer space could increase.

However, while space has always been militarised (using space for military purposes), an open conflict in space doesn't seem likely in a foreseeable future. According to James Pavur and Ivan Martinovic, space has remained relatively peaceful for a long time for three reasons: the limited access to space and the

[126] Henry, C., 2020. German Export Ban Blocks Mynaric'S First Laser Terminal From Launching In China - Spacenews. [online] SpaceNews. Available at: <https://spacenews.com/german-export-ban-blocks-mynarics-first-laser-terminal-from-launching-in-china/> [Accessed 26 November 2020].

limited number of systems in orbit for a limited number of actors reduced the probability of an open conflict (1), the use of a kinetic ASAT weapon can be detected and attributed rapidly and would have high diplomatic and political costs (2), the use of kinetic weapons in space creates debris and affects both the attacker and the victim in its use of space (3).[127]These aspects could constitute a deterrent for the use of IOS as a kinetic weapon.

Still, the landscape is changing in the space sector with an increasing number of actors and an increasing number of objects in orbit. The weaponization of outer space (placing weapons in orbit) is a rising concern as a significant number of countries are developing counterspace capabilities and most actors are observing "suspicious" activities such as unexpected manoeuvres or unwelcomed close proximity operations.

If States might think twice before using an IOS tool as a kinetic weapon, IOS could also be used as non-kinetic weapons. Indeed, the limited distance between two spacecraft could enable either intentional electronic interference or unintentional interference in case the servicer has been highjacked or hacked by a third party. Standard interface and software defined system significantly increase the risk of cyberattacks regardless of the type of IOS provided. In-orbit inspections could also come with additional cyber risks. For instance, the Australian start-up HEO Robotics is conducting in-orbit inspections by uploading a software to partner satellite which has imagery capabilities or on-board cameras. The software enables the company to remotely access the data collected by the partner satellite which takes pictures of a specific target. As a result, HEO Robotics does not need to launch a satellite in orbit.[128] In the event of a cyberattack against HEO Robotics' partner satellites, the attacker could access critical information about both HEO Robotics' clients and partner satellites.

The risk related to these non-kinetic attacks might be higher than kinetic threats since they are harder to detect and attribute, they are less regulated than kinetic weapons by international laws and the political and diplomatic consequences are also lower as most non-kinetic attacks are reversible and do not create debris, thereby keeping these attacks below the threshold of violence.[129]

Concerns related to the weaponization of outer space are legitimate as it is not the nature of the technology that has an impact but rather the intent of the user or owner of the said technology.

[127] Pavur, J. and Martinovic, I., 2019. The Cyber-ASAT: On The Impact Of Cyber Weapons In Outer Space. [online] NATO CCDCOE. Available at: <https://ccdcoe.org/uploads/2019/06/Art_12_The-Cyber-ASAT.pdf> [Accessed 27 November 2020].
[128] Kuper, S., 2020. HEO Robotics Releases Proof-Of-Concept Satellite Verification Images. [online] Space Connect Online. Available at: <https://www.spaceconnectonline.com.au/operations/4416-heo-robotics-releases-proof-of-concept-satellite-verification-images> [Accessed 27 November 2020].
[129] Pavur, J. and Martinovic, I., 2019. Op cit.

## 3.3 Business challenges

### 3.3.1 A Prospective Business

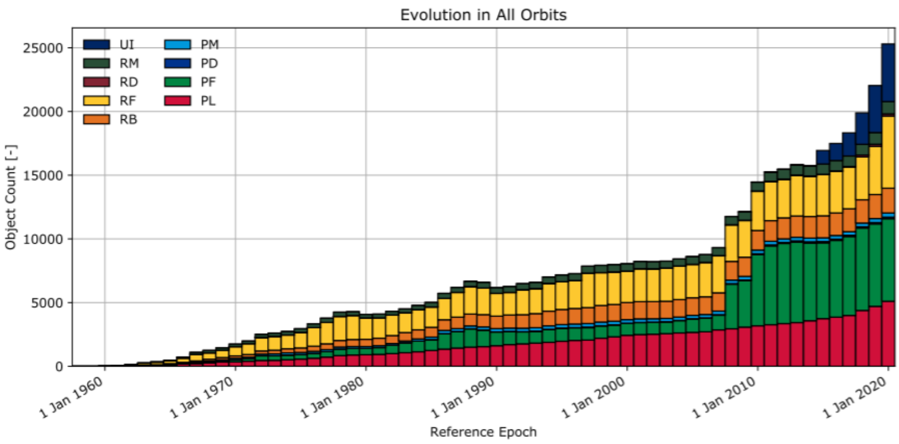
In-Orbit Servicing encompasses a broad range of capabilities, mainly based on the recurrence of RPOs. A business analysis on IOS can be based on three initial considerations:

- Regulatory and technological aspects have a great impact on the demand and the market potentials of IOS.
- The emergence of IOS already meet some existing business opportunities but remains a prospective business.
- The IOS capabilities addressed to different markets (GEO and LEO) identify distinct business cases.

Overall, IOS would unlock unique business opportunities, long-contemplated during years of technological development and human-made servicing. As a set of capabilities that includes also military applications, governments and public actors maintain a significant role in further developing the technology. Indeed, institutional actors have the leadership to adopt common regulatory framework and favour the emergence of a strong demand for IOS applications.

All in all, the value of In-Orbit Servicing business cases relies on cost-effectiveness and flexibility. The nature of In-Orbit Servicing is also potentially disruptive on various level: on one hand, the emergence and growth of IOS could accelerate some trends in the space domain, as the slowdown of orders for GEO satellites; on the other, it could provide solutions to key and predominant issues over the next decades, namely space debris mitigation and interplanetary space exploration.

Notwithstanding these general common characteristics, from a business perspective the future of IOS as a game-changer set of capabilities depends firstly on regulatory, policy-related aspects and technological challenges. A successful and thriving In-Orbit Servicing market will be shaped by the existence of shared rules and principles – both on the side of regulation and technology. Hence, the demand of IOS capabilities and the emergence of proper business models is greatly impacted by the adoption of common norms influencing IOS directly – e.g. RPOs guidelines and standardisation of “cooperative” target satellites – and indirectly – e.g. space debris mitigation.

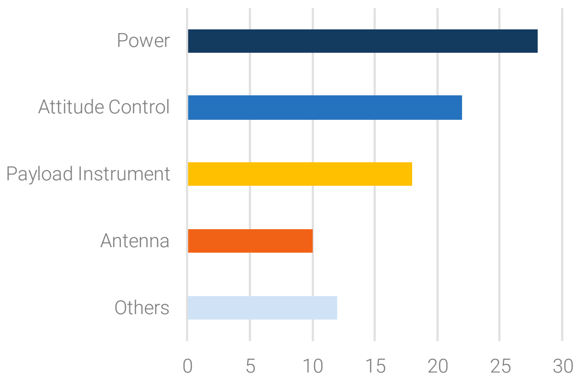



*Credit: ESA Annual Space Environment Report, 2020*

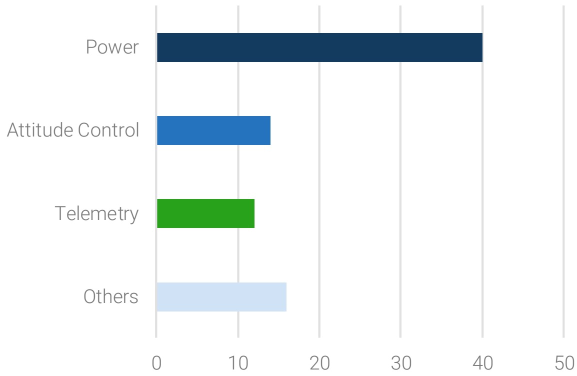
Yet, it is important to note that single episodes and trends can effectively create business or favour the conditions for rising relevance of IOS: the occurrence of unpredicted collision in orbit and the materialisation over the next decade of multiple mega-constellation projects could indeed prioritise the development of IOS capabilities, thus its full entrance in the space business. In the latest

ESA Annual Space Environment report[130], it is evidenced the evolution of the number of all objects in space, driven by the increase occurred in LEO in recent years and without taking into account scenarios involving the full deployment of constellation project over the next decade.

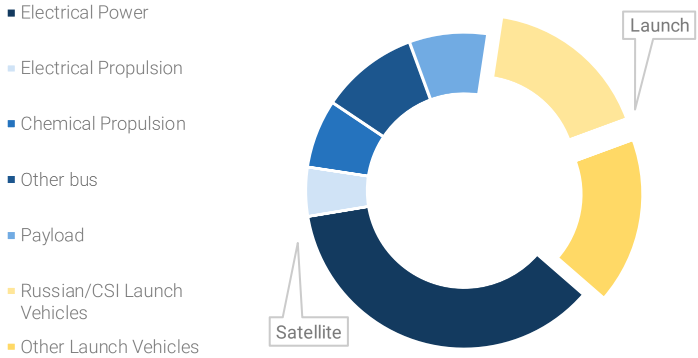
However, even without considering hypothetical scenarios, some existing business opportunities could be found, analysing satellite failures and insurance claims. It is possible to estimate that the most common cause of failure in the satellite life cycle is related to power malfunctions. A power failure results as the most common, with a 28% of the share from separation to operational phase. Considering only the operational phase, power is associated with 40% of failures, followed by attitude control and telemetry. In the "Space Insurance Update" report of 2019, the 66% of losses in the GEO satellites market since 2000 are attributed to a satellite failure (34% on the launch); within the 66%, most losses can be attributed to power and propulsion failures[131].




*Insurance Claims from the Separation to the Operational Phase (1968-2014)*




*Insurance Claims in Operational Phase (1968-2014)*




*Credit: Space Insurance Update, 2019, AXA XL. ESPI graphic elaboration*

[130] ESA. 2020. ESA'S Annual Space Environment Report. [online] Available at: <https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf> [Accessed 27 November 2020].
[131] International Union of Aerospace Insurers. 2019. Space Risk. [online] Available at: <https://iuai.org/IUAI/Study_Groups/Space_Risks/Public/Study_Groups/Space_Risk.aspx> [Accessed 27 November 2020].

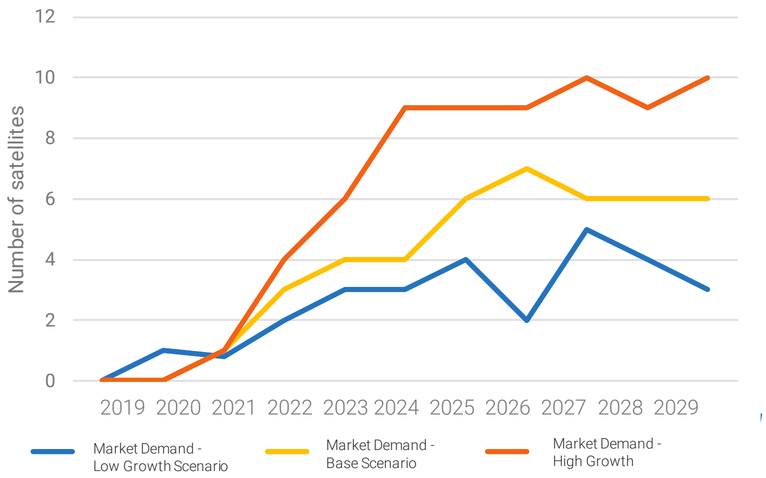
Therefore, these data emphasise the existing business opportunities, especially for IOS capabilities that provide life-extension, salvage or relocation services. In the case of a satellite experiencing a failure at the Beginning of Life (BOL) phase, IOS could provide a clear business opportunity and a cost-effective solution in terms of Return on Investment (ROI), replacement costs and capital expenditures (CAPEX). Similar conclusions may be drawn in case of a satellite at the End of Life (EOL), where expanding the ROI over an existing asset could be preferred over launching a new satellite.

At the same time, as mentioned above, the broad range of IOS capabilities addresses different markets, applying to specific characteristics and business opportunities. Hence, GEO and LEO make different business cases; life-extension services will more likely address only the GEO satellites market, while de-orbiting services respond more to the demands and properties of the LEO market. Moreover, LEO satellites are less expensive assets and could be replaced more easily then the satellites in GEO, especially considering the trend of mega-constellation deployments.

### 3.3.2 IOS/ADR Market Evaluations

Based on this sort of data and considerations, on the overall market size and its future growth, it is possible to provide market evaluations of In-Orbit Servicing. Northern Sky Research (NSR) and SpaceTec Partners have developed separate analysis. In 2019, the NSR In-Orbit Servicing Market 2nd Edition forecasted an overall amount of $4.5B of revenues from IOS by 2028[132]. According to the analysis, this share would be dominated by services addressed to the GEO market for 78% of total revenues, driven by a strong forecasted demand of life-extension services.

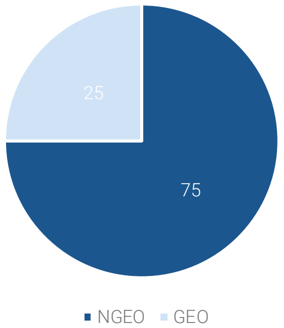
In 2020, NSR published the 3rd edition of the IOS Market, which includes also forecasts related to Space Situational Awareness (SSA)[133]. The report forecasts cumulative revenues for $3.1B by 2029. In this latest report, the demand is expected to be driven mostly by non-GEO satellites. The GEO's share of total revenues still accounts to 66%, with the demand for life-extension services showing growing trends in different scenarios.

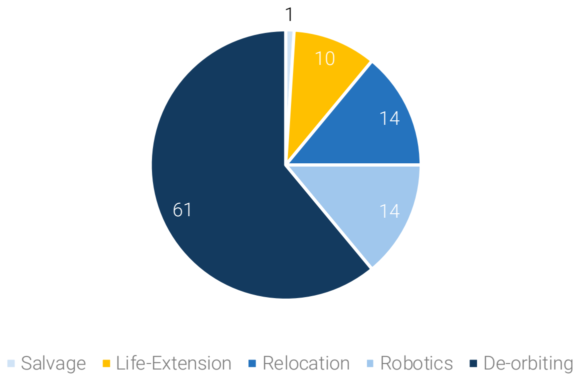



[132] Jameson, H., 2019. NSR Predicts Significant Growth Of In-Orbit Servicing Market Over Next Decade. [online] SpaceWatch.Global. Available at: <https://spacewatch.global/2019/03/nsr-predicts-significant-growth-of-in-orbit-servicing-market-over-next-decade/> [Accessed 27 November 2020].
[133] NSR. 2020. NSR Report: In-Orbit Satellite Services Pave The Way To Manage Space Assets. [online] Available at: <https://www.nsr.com/nsr-report-in-orbit-satellite-services-pave-the-way-to-manage-space-assets/> [Accessed 27 November 2020].

According to NSR, the success of the commercial MEV-1 mission and the growing attention devoted to space debris create positive conditions for future business opportunities[134].

However, the level of market readiness is not considered yet sufficient and the persistence of external constraints on the regulation and technology sides are not encouraging in the short term.




*Demand of IOS. Credit: IOS and SSA Markets, 3rd Edition Report, 2020, NSR. ESPI graphic elaboration*

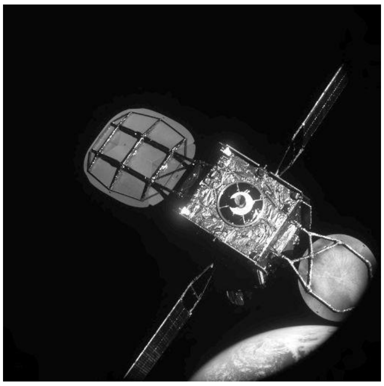
In a study conducted for ESA and related to the Clean Space initiative, SpaceTec Partners also provides an evaluation of the market opportunities for In-Orbit Servicing[135]. According to the study, a "Space Debris Mitigation technology market" could generate revenues by 2029 of approx. €3B. Moreover, a comprehensive Active Debris Removal and IOS total addressable market could generate by 2036 between €2.5 and €5B. SpaceTec Partners analyses that the LEO market would be mostly driven by an institutional demand, composed of governmental and public actors that procure the de-orbiting of owned debris, while the GEO market would be dominated by life-extension services.

Overall, the market evaluations reports highlight the emergence of a potentially booming new business in space over the next decade. The success of this market remains in part dependent on external factors and on the role of public actors to incentivise the development of the IOS capabilities. The level of awareness on IOS demonstrated by the space sector can still be considered low, even in view of increasing concerns about space debris. Consequentially, the level of competition is also low at the moment. Nevertheless, In-Orbit Servicing can be considered as a dynamic domain, with growing participation of SMEs and start-ups, among which some are also successful in attracting private investments and public interest. The growing strategic interest showed by public actors, the positive signals by private companies such as OneWeb, and not least the role that IOS could play for space exploration, could envisage In-Orbit Servicing as a successful business. In the following sections, some cases for GEO and LEO will be analysed with a business-oriented perspective, in order also to examine the sustainability of different business cases.

[134] NSR. 2020. In-Orbit Servicing: Technology And Market Readiness Undocked. [online] Available at: <https://www.nsr.com/in-orbit-servicing-technology-and-market-readiness-undocked/> [Accessed 27 November 2020].
[135] Ex-Ante Socio-Economic Impact Assessment of the European Space Agency's Clean Space Initiative, Executive Summary, 2019, SpaceTec Partners

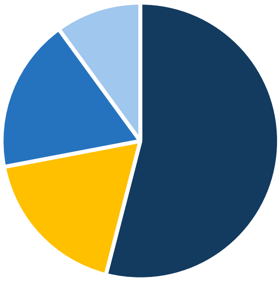
### 3.3.3 In-Orbit Servicing business in GEO

#### The success of the MEV-1 and business considerations



*Credit: Northrop Grumman*

In the course of 2020, In-Orbit Servicing has noticeably experienced a boost due to the success of the first commercial mission, the MEV-1 operated by Northrop Grumman. With successful docking with an Intelsat's target satellite, the MEV-1 demonstrated the readiness of the technology, increasing also the awareness and the readiness of the market[136]. In August 2020, an Ariane 5 rocket launched in orbit the MEV-2, expected to conclude its orbit transfer and dock with another Intelsat satellite (IS-1002) in 2021[137]. Moreover, through its subsidiary SpaceLogistics, Northrop Grumman is developing other capabilities to expand its portfolio of IOS applications, through with the less expensive Mission Extension Pods (MEP) and the more advanced Mission Robotics Vehicle (MRV).




*Serviceable GEO Satellite Anomalies. Credit: Intelsat. ESPI graphic elaboration*

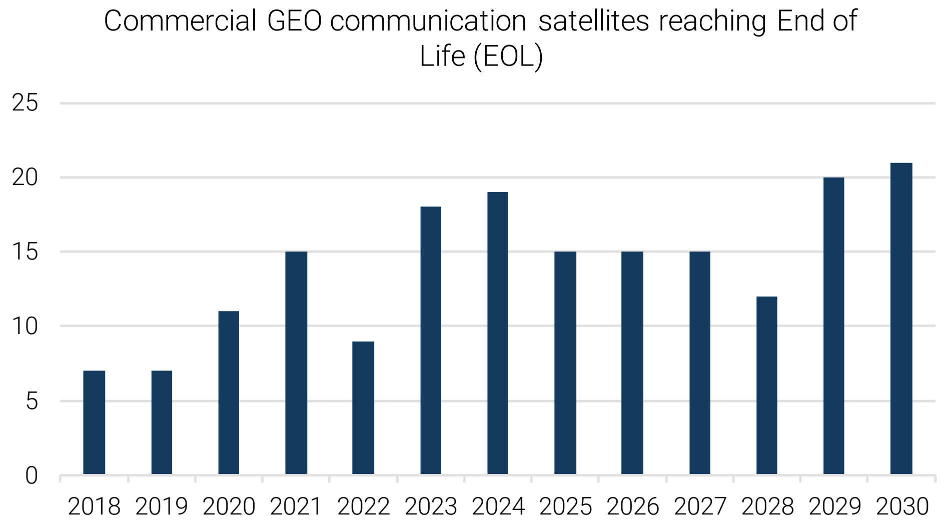
The costs of the MEV-1 services are approx. $70M, over the initial duration of 5 years of the mission ($13-14M per year) that could also be extended by an agreement between Intelsat and Northrop Grumman. By docking with the IS-901 utilising the liquid apogee engine, the U.S. manufacturer demonstrated also the existence of a potential large market for life-extension services, as many GEO satellites might present such makeshift docking equipment – approximately 80% of GEO satellites, according to the company. The Intelsat 901 serviced satellite is in operation in GEO since 2001 and would now reach its EOL in 2025. In economic terms, the mission can be considered a success: Intelsat increased ROI on an existing and well-functioning asset, saving CAPEX in the order of $200-400M for the replacement of the GEO telecommunication satellite – in a period of financial issues for Intelsat that led to the restructuring of debt and after experiencing in 2019 the loss of the I-29e satellite after only three-years from launch, which costed the company between $350-500M of losses in revenues.

Yet, the decision to delay new expenditures to replace a GEO satellite must cope with other technological factors, related to innovation. A new satellite can benefit from more advanced technology that could lead to higher commercial revenues. In this case, the cost per year of the servicing mission may not reach the breakeven point and the satellite operator could prefer to replace the satellite at its EOL. Moreover, it can

[136] Northrop Grumman Newsroom. 2020. Northrop Grumman Successfully Completes Historic First Docking Of Mission Extension Vehicle With Intelsat 901 Satellite. [online] Available at: <https://news.northropgrumman.com/news/releases/northrop-grumman-successfully-completes-historic-first-docking-of-mission-extension-vehicle-with-intelsat-901-satellite> [Accessed 27 November 2020].

[137] Northrop Grumman Newsroom. 2020. Northrop Grumman'S Second Mission Extension Vehicle And Galaxy 30 Satellite Begin Launch Preparations In French Guiana. [online] Available at: <https://news.northropgrumman.com/news/releases/northrop-grummans-second-mission-extension-vehicle-and-galaxy-30-satellite-begin-launch-preparations-in-french-guiana> [Accessed 27 November 2020].

be considered that the space industry could perceive the IOS business and the life-extension services as a threat of cancellations and slowdown of orders, leading to scepticism over the IOS benefits.[138]




*ESPI graphic elaboration (data source: Union of Concerned Scientists)*

Nonetheless, as mentioned before IOS can provide unique solutions in case of BOL failures, assuring considerable ROI. Furthermore, the overall number of satellites reaching EOL over the next decade, regardless of their operators, seems to indicate the existence of a sustainable business case and a large total addressable market. Not least, the data concerning anomalies and failures of GEO satellites could reinforce the case for IOS.

### Other significant developments in GEO

Besides the market potential, the development of IOS capabilities from Northrop Grumman and other companies such as Maxar and MDA has also leveraged on the close attention paid by NASA and DARPA on IOS. NASA's On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) and DARPA's Robotic Servicing of Geosynchronous Satellites (RSGS) mission are clear examples of the institutional interest in In-Orbit Servicing. Previously called Restore-L, under the OSAM-1 mission NASA awarded Maxar with a $142M contract in January 2020[139]; then, in November 2020 Maxar selected MDA as subcontractor for the mission[140]. In addition, in March 2020 DARPA selected Northrop Grumman for the development of its RSGS programme, also focused on refuelling and in-orbit demonstrations[141]. These initiatives are critical to potentially expand the business opportunities for further IOS missions, for both commercial and institutional actors.

Despite these positive indications, the IOS business area is not yet fully expanded to Europe. In the aftermath of the MEV-1 success, during the Satellite 2020 Conference Airbus presented some concerns

[138] Benedict, 2013. Intelsat General Corporation. American Institute of Aeronautics and Astronautics, Inc.
[139] Henry, C., 2020. Maxar Wins $142 Million NASA Robotics Mission - Spacenews. [online] SpaceNews. Available at: <https://spacenews.com/maxar-wins-142-million-nasa-robotics-mission/> [Accessed 27 November 2020].
[140] Werner, D., 2020. Maxar Taps MDA For Robotic Satellite Servicing Technologies. [online] SpaceNews. Available at: <https://spacenews.com/mda-robotics-for-spider-osam-1/> [Accessed 27 November 2020].
[141] Northrop Grumman Newsroom. 2020. Northrop Grumman'S Wholly Owned Subsidiary, Spacelogistics, Selected By DARPA As Commercial Partner For Robotic Servicing Mission. [online] Available at: <https://news.northropgrumman.com/news/releases/northrop-grummans-wholly-owned-subsidiary-spacelogistics-selected-by-darpa-as-commercial-partner-for-robotic-servicing-mission> [Accessed 27 November 2020].

about the IOS market potential and hesitance about the sustainability of the business case[142]. Yet, between April and July 2020 Xtar and Hisdesat expressed the actual possibility to purchase life-extension service on the SpainSat and Xtar-Eur satellites, launched in 2005 and 2006 and reaching their EOL[143] [144]. In a 2019 conference, Thales Alenia Space commented as well on the feasibility of IOS missions, remarking that the involvement in the business was mainly dependent on the presence of institutional actors as anchor customers[145]. Moreover, the engagement of the European Union for the demonstration of key servicing technologies – reported in the section below – could bring up the TRL and support the emergence of multi-purpose vehicles with a leading role for Thales Alenia Space.

Meanwhile, start-ups also start to weigh in the IOS business area. The US based Orbit Fab, founded in 2018, announced in November 2020 an agreement to launch its "Tanker-001 Tenzing", a satellite refuelling depot developed also thanks to a contract from the U.S. Air Force[146]. Moreover, the Israeli start-up Effective Space Solutions, focused on life-extension, has been acquired by Astroscale U.S. in June 2020[147]. By the acquisition, Astroscale entered also the IOS market, besides developing ADR capabilities, expanding its core business idea of space sustainability.

In summary, the business case for life extension and similar services in GEO is clear. GEO satellites and launches are expensive investments and the decision to extend the life of a GEO satellite is primarily economic. Ordering and launching a new satellite also entail licensing and insurance, which is resource intensive for satellite owners. The cost/benefit ratio is clear for GEO satellites: if the currently orbiting satellite could earn revenues exceeding the cost of the life extension mission, the operator has a strong incentive to choose the mission rather than ordering a new satellite. This will increasingly be the case as life extension technologies are de-risked and operators become more comfortable with the concept.

### 3.3.4 Active Debris Removal business in LEO

Compared to the IOS business opportunities in GEO, the business cases for servicing missions in LEO – mostly related to Active Debris Removal – are much more dependent on public actors and governments as customer to emerge and advance.

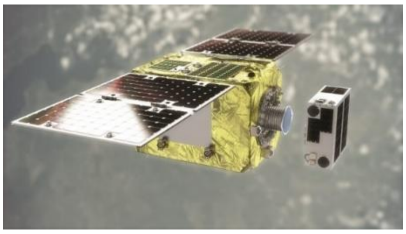
The increasing number of satellites in LEO is mostly driven by smaller, cheaper satellites, including <500 kg small satellites and CubeSats. Therefore, there is no strong incentive to invest further funds to repair or upgrade the satellites; a replacement satellite would be of similar cost. There is even less incentive to pay to dispose of the satellite, mostly because there is no regulatory framework compelling operators to do so.

[142] Henry, C., 2020. Airbus Impressed By Northrop Grumman, But Remains Undecided On Satellite Servicing - Spacenews. [online] SpaceNews. Available at: <https://spacenews.com/airbus-impressed-by-northrop-grumman-but-remains-undecided-on-satellite-servicing/> [Accessed 27 November 2020].
[143] Henry, C., 2020. Xtar, Hisdesat Weigh Life Extension For Aging Satellites - Spacenews. [online] SpaceNews. Available at: <https://spacenews.com/xtar-hisdesat-weigh-life-extension-for-aging-satellites/> [Accessed 27 November 2020].
[144] Henry, C., 2020. Xtar Sells Satellite To Hisdesat, Shifts To Lease Agreement - Spacenews. [online] SpaceNews. Available at: <https://spacenews.com/xtar-sells-satellite-to-hisdesat-shifts-to-lease-agreement/> [Accessed 27 November 2020].
[145] Henry, C., 2019. Thales Alenia Space Mulls Satellite Servicing Venture - Spacenews. [online] SpaceNews. Available at: <https://spacenews.com/thales-alenia-space-mulls-satellite-servicing-venture/> [Accessed 27 November 2020].
[146] Werner, D., 2020. Orbit Fab To Launch First Fuel Tanker In 2021 With Spaceflight - Spacenews. [online] SpaceNews. Available at: <https://spacenews.com/orbit-fab-to-launch-with-spaceflight/> [Accessed 27 November 2020].
[147] Astroscale. 2020. Astroscale U.S. Enters The GEO Satellite Life Extension Market. [online] Available at: <https://astroscale.com/astroscale-u-s-enters-the-geo-satellite-life-extension-market/> [Accessed 27 November 2020].

In light of this, deorbiting is not driven by the value of the satellite. Instead, the value of deorbit and debris removal must be assessed by the damage caused to the space environment. This includes the increased risk of conjunction to other operators, risk to the ISS and potential for collisions to cause large increases in debris. The beneficiary of investing in a deorbit system, or an active debris removal mission, is less the owner of the satellite but the rest of the space industry. There is an economic cost to the tragedy of the commons. As a result, recognising the importance of the economic value of LEO and its sustainability is crucial to advancing the case for active debris removal.

However, a total addressable market in LEO has been evaluated as well, especially because of the large numbers of approved and deployed satellites part of mega-constellation projects. Indeed, apart from space agencies, a potential demand for ADR services can also include satellite operators and insurance companies, as it could reduce risks to which insurers are exposed to. Still, more than in GEO, the sustainability and success of ADR business cases require commercial incentives and public anchor customers that act as market creators, on top of a clear regulatory framework and solid technological solutions.

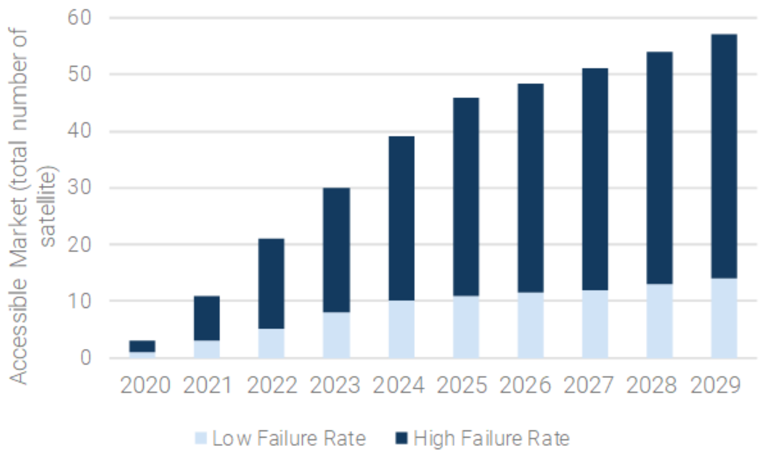
### The case of Astroscale



*Credit: Astroscale*

In this realm, there are several projects and demonstrations missions. Astroscale represents a prominent example as the company has raised approx. $200M, securing $51M in a recent Series E round and backed by private and public funds[148]. Astroscale recently announced the plan to conduct the first commercial ADR mission in March 2021[149]. The End-of-Life Services by Astroscale-demonstration (ELSA-d) mission is expected to demonstrate several capabilities related to the removal of a target satellite or uncooperative debris. Moreover, in February 2020 Astroscale has been selected by JAXA for the Commercial Removal of Debris Demonstration (CDR2) project, expected by 2023[150]. The CDR2 is a two-phase mission highly considered by JAXA and by Japan, that presented its plan on space sustainability also at the G-20 Summit held in Osaka in 2019[151]. Not least, in January 2020 Astroscale was awarded a grant of U$4.5M from the Tokyo Metropolitan Government under the "Innovation Tokyo Project" aimed at supporting the commercialisation of ADR services[152].

[148] Werner, D., 2020. Astroscale Raises $51 Million In Series E, $191 Million Overall - Spacenews. [online] SpaceNews. Available at: <https://spacenews.com/astroscale-e-round/> [Accessed 27 November 2020].
[149] Werner, D., 2020. Astroscale Announces 2021 Soyuz Launch Of ELSA-D Mission. [online] SpaceNews. Available at: <https://spacenews.com/astroscale-elsa-d-launch-2021/> [Accessed 27 November 2020].
[150] Astroscale. 2020. Astroscale Selected As Commercial Partner For JAXA'S Commercial Removal Of Debris Demonstration Project. [online] Available at: <https://astroscale.com/astroscale-selected-as-commercial-partner-for-jaxas-commercial-removal-of-debris-demonstration-project/> [Accessed 27 November 2020].
[151] Siripala, T., 2020. Japan'S Space Dream? Cleaning Up The Mess.. [online] Thediplomat.com. Available at: <https://thediplomat.com/2020/03/japans-space-dream-cleaning-up-the-mess/> [Accessed 27 November 2020].
[152] Astroscale. 2020. Astroscale Awarded Up To US $4.5 Million Grant From Tokyo Metropolitan Government To Commercialize Active Debris Removal Services. [online] Available at: <https://astroscale.com/astroscale-awarded-up-to-us-4-5-million-grant-from-tokyo-metropolitan-government-to-commercialize-active-debris-removal-services/> [Accessed 27 November 2020].




*Credit: Astroscale. ESPI graphic elaboration*

Overall, in a paper presented at the IAC 2019, Astroscale analysed the market potential for ADR, identifying a "serviceable addressable market" and a "serviceable obtainable market"; in this last case, the company expects that by 2030 approx. 15 to 50 satellites per year could be removed from orbit – estimation depending on several factors, such as the low or high failure rate, post-mission disposal and mitigation standards[153].

### Europe assumes leadership

Besides Astroscale, Europe at large is leading the efforts to support and make sustainable the business cases for ADR, with a predominant role of public actors. Securing funding for ClearSpace-1, ESA procured the ADR service and is supporting a mission, expected by 2025, whose total costs are assessed at approx. €120M[154]. The Swiss start-up ClearSpace has funding for €70M for the first three-years and is then expected to find a second agreement with ESA for the latest phases of the mission design. Moreover, ClearSpace has raised so far approx. €2M and in June 2020 has been selected by the Microsoft Global Social Entrepreneurship Program, devoted to support in multiple ways innovative start-ups[155]. Apart from the Clean Space initiative, ESA recently signed a contract worth €2.5M with the Polish PIAP Space for the TITAN project[156], aimed at developing a multi-articulated robotic arm out of the TRL "valley of death" and with the purpose of both debris removal and potential servicing[157].

The European Union supported the demonstration of several ADR capabilities, initially under the H2020 programme Remove Debris, led by the Surrey Space Centre with other 8 partners including Airbus[158]. Financed by the EU with approx. €7M over a total budget of €15M, Remove Debris conducted in 2018 a

[153] Brettle et al., 2019. Astroscale Holdings. IAC-19, A6,10-B4.10,8, x49992
[154] Henry, C., 2019. Swiss Startup Clearspace Wins ESA Contract To Deorbit Vega Rocket Debris - Spacenews. [online] SpaceNews. Available at: <https://spacenews.com/swiss-startup-clearspace-wins-esa-contract-to-deorbit-vega-rocket-debris/> [Accessed 27 November 2020].
[155] Startupticker. 2020. Swiss Startup Clearspace Gets Support From Microsoft To Clean Up Space Startupticker.Ch | The Swiss Startup News Channel. [online] Available at: <https://www.startupticker.ch/en/news/june-2020/swiss-startup-clearspace-gets-support-from-microsoft-to-clean-up-space#.XvNqltFLEpk.twitter> [Accessed 27 November 2020].
[156] Jasińska, J., 2020. Space Agency Signs 2.5 Million EUR Contract For TITAN Robotic Arm Project. [online] The first news. Available at: <https://www.thefirstnews.com/article/space-agency-signs-25-million-eur-contract-for-titan-robotic-arm-project-14582> [Accessed 27 November 2020].
[157] PIAP Space. 2020. TITAN Project. [online] Available at: <https://piap.space/projects/titan-project/> [Accessed 27 November 2020].
[158] University of Surrey. 2020. Removedebris Mission. [online] Available at: <https://www.surrey.ac.uk/surrey-space-centre/missions/removedebris> [Accessed 27 November 2020].

series of demonstration for de-orbiting cooperative and uncooperative satellites, including an experiment initiated after deployment from the ISS[159], and considered still today a critical building block for the solution of the space debris issue[160].

More recently, the European Union has endeavoured to consolidate the space industry's and its own engagement into the broad range of IOS capabilities, keeping a special focus on the de-orbiting and removal. In fact, through H2020 the EU had funded the European Robotic Orbital Support Services (EROSS) project, led by Thales Alenia Space with other 11 partners[161]. With funding of almost 4M€, EROSS aims to demonstrate a full set of servicing capabilities in LEO and GEO, with the goal of boosting the level of technology maturity[162]. The EROSS consortium builds on several previous Operational Grants in the field of space robotics technologies of the Strategic Research Cluster (SRC) as well as on the expertise of the European space industry, including GMV as well as the Polish company PIAP Space. EROSS is soon planned to arrange the ground demonstration of the key technologies involved in the project. Moreover, the EU will fund the follow-up EROSS+, a 2-year project expected to be launched from early 2021 and to move forward with its phase A/B1 demonstration mission of IOS capabilities with again a leading involvement of Thales Alenia Space, that is said to aim for the commercialisation of its Multi-Purpose Servicing Chaser in 2021.

Finally, worth mentioning are also European start-ups, such as the French Exotrail and the Italian D-Orbit, two start-ups that raised considerable investments over the last years and that focus also on propulsion and de-orbiting systems. To conclude, as IOS capabilities are highlighted also in view of space exploration – especially for the refuelling, in-orbit assembly and manufacturing capabilities – innovative and forward-looking ideas are being developed. Among these, for instance, Orbit Recycling aims to de-orbit upper stages debris taking them to the Moon for further In-Situ Resource Utilisation (ISRU) of aluminium[163].

### Final considerations

The support of public actors acting as anchor customers and market creators is necessary for the demonstration of the ADR capabilities. The engagement of the European Union through H2020 and several projects on space robotics technologies, with a focus also on assembly and manufacturing for ISRU and planetary exploration, could eventually support the emergence of large IOS capabilities, including de-orbiting and active debris removal.[164]

However, while the business case for GEO satellites is clear, the financial gain in contracting de-orbiting services for LEO satellites is more complicated to assess. The ADR business case will be more difficult to emerge, as ADR requires commercial incentives and is dependent on conferring value to the sustainability of the space environment.

[159] European Commission. 2020. A Low Cost Active Debris Removal Demonstration Mission - Removedebris. [online] Available at: <https://cordis.europa.eu/project/id/607099> [Accessed 27 November 2020].
[160] European Commission. 2020. A Solution To The Problem Of Space Junk. [online] Available at: <https://ec.europa.eu/research/infocentre/article_en.cfm?artid=53365> [Accessed 27 November 2020].
[161] European Commission. 2020. European Robotic Orbital Support Services. [online] Available at: <https://cordis.europa.eu/project/id/821904> [Accessed 27 November 2020].
[162] EROSS. 2020. Home - EROSS. [online] Available at: <https://eross-h2020.eu/> [Accessed 27 November 2020].
[163] Koch, F., 2020. Combining ISRU And Space Debris For Constructions On The Moon. [online] ESA. Available at: <https://ideas.esa.int/servlet/hype/IMT?documentTableId=45087607016142164&userAction=Browse&templateName=&documentId=02688516b78ba35b5271c5a1d19a0f80> [Accessed 27 November 2020].].].].
[164] European Commission. 2020. Horizon 2020. [online] Available at: <https://cordis.europa.eu/search?q=contenttype%3D%27project%27%20AND%20programme%2Fcode%3D%27SPACE-12-TEC-2018%27&p=1&num=10&srt=/project/contentUpdateDate:decreasing> [Accessed 27 November 2020].

Over the next decade, **the adoption of clear and stricter space debris mitigation rules, together with the emergence of mega-constellation, may foster the business case for ADR and indicate the existence of a proper business area open for commercial services, particularly in LEO.**

Indeed, NSR outlined in its report that the lack of strict regulations is one of the biggest constraints to the emergence of an IOS market. According to Leena Pivovarova, NSR Analyst, government support for IOS and a clear legal framework would facilitate IOS market expansion and increase investors' confidence.[165] Similarly, Shagun Sachdeva, NSR Analyst, believes that international regulations and enforcement methods could accelerate the business case for IOS, in particular de-orbiting.[166]

Furthermore, the existing non-binding recommendations and best practices established by the ITU or IDAC regarding debris mitigation and EOL manoeuvres are not implemented by the majority of satellite operators. For instance, ESA's space environment report reported that only half of all satellites are properly disposed at the end of their lifetime.[167] Therefore, while space debris can drive institutional demand for IOS, the lack of regulations regarding both IOS and space sustainability does not constitute an economic driver for commercial IOS, in particular ADR.

At the moment, the value of deorbiting is merely linked to ensuring the usability of LEO and protecting the LEO economy, therefore **another way to build the business case for ADR in LEO might be for insurance providers to incentivise the use of IOS to ensure space sustainability.** Drawing from Harrington's argument on debris mitigation[168], insurers could reduce insurance premiums for operators that use IOS services either for maintenance and repair, de-orbiting or life extension. Additional premiums could be computed for companies that are not using IOS when possible. **These initiatives might help create a commercial demand for IOS.** However, Victoria Samson et al. have pointed out that while insurance providers could be relevant actors to encourage responsible behaviours in order to ensure space sustainability, the space insurance market is highly competitive and insurers are reluctant to raise prices out of fear that space companies chose another insurer. As a result, this carrot and stick approach might not be seen as profitable from the insurer's perspective. In addition, in-orbit liability insurance (insurance against damage caused to another satellite) is not systematic for satellite operators and in-orbit operations have not been historically insured. This aspect reduces the possibilities for insurers to encourage the use of IOS to improve space sustainability.[169]

Finally, one other long-term alternative to build the business case for ADR in LEO would be technological. Further concepts such as **mass deorbiting**, or multiple deorbital missions on a single rideshare launch, could also drive down costs and enable the market to grow. However, each have their own technical challenges to overcome and the feasibility remains to be investigated.

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[165] Satellite markets. 2019. EMEA Page Industry Trends - News Analysis - Market Intelligence And Opportunities NSR Report Forecasts US$ 4.5 Billion In Cumulative Revenues From In-Orbit Satellite Services By 2028. [online] Available at: <http://satellitemarkets.com/market-trends/nsr-report-forecasts-us-45-billion-cumulative-revenues-orbit-satellite-services-2028> [Accessed 10 December 2020].

[166] Sachdeva, S., 2020. NSR: A Small Step For On-Orbit Servicing Markets ... New FCC Rules. [online] Satnews. Available at: <http://www.satnews.com/story.php?number=1711403494> [Accessed 10 December 2020].

[167] ESA. 2020. ESA'S Annual Space Environment Report. [online] Available at: <https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf> [Accessed 27 November 2020].

[168] Harrington. A., 2015. Debris Mitigation as An Insurance Imperative. 66th International Astronautical Congress. Jerusalem, Israel, p.6

[169] Samson. V., Wolny. J., Christensen, I. 2018. Can the Space Insurance Industry Incentivize the Responsible Use of Space? 69th International Astronautical Congress, Bremen, Germany, p. 2-5

**As a result, at the moment, there is no incentive or economic driver to contract ADR services in LEO as long as there is not a coherent a legal and regulatory framework accounting for the full life cycle of LEO satellites from launch to disposal.**

The table below breaks down some of the differences of the ADR business case between GEO and LEO:

| | GEO | LEO |
|---|---|---|
| Major application | Life extension | De-orbiting |
| Potential demand | Mostly commercial actors | Mostly institutional actors |
| Expected demand | 10% of cumulative demand for IOS by type of service (NSR data) | 61% of cumulative demand for IOS by type of service (NSR data) |
| Business opportunity | Rising number of satellites reaching EOL | Public actors' concern to mitigate debris<br>Skyrocketing number of assets in LEO |
| Business strengths | Rising commercial interest (Intelsat, Iridium, etc) | |
| Business weaknesses | Fear of slowdown of new satellite orders | Cheap assets to replace |
| Business threats | Collisions<br>Lack of regulations | Collisions<br>Lack of regulations |
| Successful missions | MEV-1 | None |
| Missions planned in the next 3 years | Yes | Yes |
| Market leaders | Northrop Grumman | Astroscale |
| Regulations | None | None |

*Table 2: Compared analysis of ADR business cases in LEO and GEO*

# 4 Conclusion

## Summary of findings

The rising interest in in-orbit services in the last few years, including private initiatives, has started to raise questions about the emergence of a true commercial market for IOS. The lack of a clear business case as well as technological difficulties have long questioned the feasibility and the profitability of IOS because of the high cost of institutional missions conducted in the 20th century.

There has long been a "chicken-and-egg" debate about the emergence of in-orbit services, assuming that as long as satellites were not designed to be serviced, IOS would be impossible. Whether it was seen as a cause or an effect, there was also no reason for satellite manufacturers to take servicing into account in the design and production of their space systems in the absence of a market for IOS.[170] However, IOS are currently feasible even if most satellites are not designed to be serviced. Systems "serviceable by design" are emerging such as the integration of grappling fixtures on OneWeb satellites. In addition, seeing the increased interest in IOS, some companies such as OrbitFab have solved the problem by planning to launch an in-orbit fuel depot (or space gas station) to create a supply that will drive the demand for fuel in orbit.[171]

Therefore, three generations of IOS can be identified:

- The early IOS market is characterised by crewed missions and extravehicular activities mostly conducted by Nations-Sates such as the United States and the Soviet Union (then Russia) on their own satellites or on the International Space Station.
- The current IOS market is characterised as an emerging market in which satellites in orbit can be serviced but are not designed as such. As a result, missions are specific and tailored for one system. This market has a high demand for refuelling as most satellites in orbit have fuel propulsion limitations.
- The potential future IOS market is characterised as a market in which satellites will be designed to be serviced and both hardware and software will be more standardised and interoperable, thereby facilitating and accelerating the development of other IOS technologies and the emergence of new private ventures in this market. The market will probably have a lower demand for refuelling as an increasing number of satellites will be equipped with electric propulsion systems.

The biggest challenges regarding in-orbit services are not necessarily technological but rather legal and commercial.

Indeed, IOS are now reaching a high Technological Readiness Level. The key enabling technologies are being developed and are not necessarily perceived as the biggest constraints by operators for the development of basic IOS. Still, it must be noted that servicing a non-cooperative target is seen as more challenging technologically. More advanced services such as recycling or manufacturing require additional developments and demonstrations before they can be operational.

[170] NASA. 2010. Op cit.
[171] Werner, D., 2020. Orbit Fab To Launch First Fuel Tanker In 2021 With Spaceflight - Spacenews. [online] SpaceNews. Available at: <https://spacenews.com/orbit-fab-to-launch-with-spaceflight/> [Accessed 10 December 2020].

However, legal challenges are more present as the lack of regulations and best practices add a layer of uncertainty for IOS operators and clients regarding liability issues in case of collision or accident while providing services in orbit.

While there is a current need for in-orbit services, there is a difficulty to convince commercial actors of the profitability of this business as previous missions were mostly occasional and therefore not profitable. There is also a need to convince satellite operators of the financial benefits of contracting IOS such as the reduction of insurance premiums if their systems can be serviced, additional revenues generated by a satellite if it can be repaired, reconfigured or extended.

## In-orbit services: a representative case of the changing landscape in the global space sector

Breakthrough technologies. It could be assessed that in-orbit services are representative of the changing landscape in the global space sector with the miniaturisation of space systems and the development of breakthrough technologies that will fundamentally change the way satellites are designed and operated.[172] IOS often involve a space tug, a small autonomous spacecraft which provides services to repair satellites or extend their life. As a result, IOS significantly impacts the life cycle of space systems through life extension, repair and reconfiguration, not to mention assembly and recycling.

New Space entered the IOS market. Similar to other fields in the space sector, the IOS market used to be the sole domain of institutional actors and is now accessed by commercial actors, including start-ups which are launching fully commercial initiatives such as SpaceLogistics' MEV.

From militarization to weaponization of outer space. The weaponization of outer space is a growing concern in which IOS are perceived as a potential enabler. The use of robotic arms, harpoons, nets or RPO to conduct attacks or gather intelligence on an enemy's satellites has been the subject of discussions as ADR and in-orbit inspection missions are being launched. In this context, IOS might both be a driver for the institutional demand of in-orbit services as well as an impediment for commercial actors who might perceive these in-orbit operations as unsafe and unprofitable.

Rising interest in the exploration and use of space resources. IOS, and more particularly in-orbit manufacturing consists in a new market in which space resources can be transformed into space systems or components for commercial purposes. For these innovative processes, there are both an institutional demand related to exploration programs as well as a commercial demand from start-ups interested in the appropriation of space resources.

## In-orbit services: a representative case of the challenges in the European space sector

Challenges for the improvement of SSA data. Developing prosperous and reliable in-orbit services requires improved capabilities in the field of Space Situational Awareness and Space Traffic Management, which was already identified as a challenge and as an objective by European space stakeholders.[173] Current IOS often require going to a graveyard orbit to provide the service in order not to damage operational satellites in GEO, which is both a technical and financial constraint for commercial actors. Better SSA data is a pre-requisite for the development of profitable and secure IOS.

[172] Aliberti, M., et al., 2020. European Strategy in a Global Context. ESPI Report, Executive Summary
[173] Ibid.

**Challenges for Europe's competitiveness.** Europe is facing competition from both traditional space powers (US, China, Russia) and emerging space nations (Australia, Israel, etc) which are entering the IOS market. In addition, exports regulations such as ITAR might impact the profitability of European IOS ventures in case they include foreign components or equipment, especially if exports are a key factor in the lucrativeness of European programmes. Moreover, the development of system standards such as grapple fixtures or software interfaces could significantly impact Europe's competitiveness if the standards are defined by foreign actors and are different than the systems currently developed in Europe.

**Challenges for the creation of international standards and best practices.** The trend seems to tend towards a bottom-up approach for the establishment of standards, best practices and confidence building measures with industry-led initiatives such as CONFERS or the Space Safety Coalition. While constraining regulations and legally binding norms are unlikely to be adopted in the field of IOS, there is an interest for Europe to take part in international discussions related to the establishment of standards in order to remain competitive.

**Challenges for a coordinated approach on IOS.** European countries are developing IOS, but they have different priorities and strategies. While some countries are more interested in the economic benefits, others are more focused on defence-related aspects. However, this should not be a constraint for the development of an IOS market as key enabling technologies are standard space technologies that are not exclusively linked to defence. Therefore, European countries or industries should be able to collaborate regardless of their priorities.

The EU, through the Horizon 2020 Programme, is supporting the development of IOS in a collaborative approach by gathering European industries to develop or improve a system and support a business case. This kind of projects enhances information-sharing and exchange of expertise between European actors and can serve as a springboard for the demonstration of the feasibility and reliability of IOS, thereby supporting the creation of a stable IOS market with a sustainable commercial demand.

Supporting European industries through such programmes could be reinforced in order to create a real commercial market for IOS, especially in light of the adoption of the EU Industrial Strategy in November 2020 which states that : *"Highlights the importance of Union space policy, especially in terms of improving European industrial space capacities and unlocking the potential of synergies with other key sectors and policies, in particular so as to develop cutting-edge technologies and accompany the industrial transformation."* [174] IOS could be seen as cutting-edge technologies worth supporting by European institutional actors.

## Future outlook

Overall, it is this report's assessment, that in-orbit operations will develop in the near future. There is not a single overarching business case for IOS but rather a heterogeneous set of emerging institutional and private ventures that are driven by diverse needs. However, the nascent nature of this market does not yet enable to fully assess how and when it will develop, in particular for the following services:

- De-orbiting services are not commercially attractive at the moment, but an economic rationale will emerge at some point. The case for de-orbiting must be addressed against the future cost of using space unsustainably. Considerations should be given to the development of a regulatory framework

[174] European Parliament. 2020. A New Industrial Strategy For Europe. [online] Available at: <https://www.europarl.europa.eu/doceo/document/TA-9-2020-0321_EN.pdf> [Accessed 27 November 2020].

on debris mitigation so that current European-funded ADR projects go beyond technological demonstrations and really contribute to the emergence of a commercial market in which operators would have to include ADR in their plans.

- Life extension services will increase in the near future as the business case has been proven and the technology demonstrated, and marginal growth is expected. Future opportunities to build upon this include refuelling and upgrading satellites on orbit.
- In-orbit assembly and in-orbit manufacturing needs are mostly absent at the moment but will develop in the framework of exploration missions for robotic resupply missions or exploitation of *in situ* resources.

### In this context, Europe has to position itself in this market.

This requires some advanced reflections to be initiated by institutions in order to properly frame these activities. Indeed, IOS raise a number of legal and regulatory challenges, technological standardisation issues as well as security-related aspects that should be dealt with by public actors for the IOS market to thrive.[175]. Currently, Europe has not defined clear positions in these matters and some initiative should be undertaken in order to set some common grounds to be pushed forward in international discussions. Some interesting reflections have already been led by ESA in particular as well by some member states and academia, paving the way for joint positions based on shared views and concerns, at least for civil and commercial applications.

At the image of what is currently taking place in the United States, it is expected that private operators will take the lead on such markets to provide services on a commercial basis. Indeed, the deployment of publicly owned and operated space infrastructures for the delivery of such services expected is highly unlikely. As a consequence, institutions, and in particular space agencies will act there as consumers procuring off-the-shelf services handled by private operators, rather than customers in full control of technical developments and operations. ESA, with the specific implementation of the ADRIOS mission, has properly anticipated this trend.

It is clear that, in order to provide the favourable market conditions, the public sector has a major role to play:

- First, by supporting developments of critical and enabling technologies through public R&D programmes up to a sufficient readiness level so as to make them available for operational applications,
- Second, by identifying potential market perspectives for the procurement of IOS to meet the needs of future public space programmes,
- Third, by establishing appropriate procurement policies to encourage the investments to be made by the private sector and favour the positioning European industry through long term commitments and anchor tenancy arrangements,
- Fourth, by provisioning budgets accordingly in order to ensure predictability and stability to the market.

Furthermore, as space is becoming more contested and congested, transparency and confidence building measures are key to monitor the IOS missions that are being carried out, ensure accountability and avoid suspicions of hostile behaviours. In this respect, commercial developments should be conducted in an

[175] ESPI. 2020. In-Orbit Servicing: Challenges and Implications of an Emerging Capability. ESPI Brief 38

open way with invitations to be observed as it was the case during the MEV-1 docking process.[176] However, this shall be combined with strong SSA capabilities that are not yet fully available in Europe.

Looking at the future, it is expected that IOS projects will increase and planned missions will be successfully launched. If Europe wants to seize the opportunity to position itself as an active player in this domain, some ambitious decisions should be made shortly. Obviously, the potential growth of IOS commercial markets can hardly justify on its own the kind of investment needed to take up such challenge. However, IOS will probably be enablers in many innovative ways of dealing with future space missions. In this respect, they should not be disregarded. Furthermore, many IOS-related technologies are key to many critical space applications. Therefore, IOS should not be considered in isolation, but rather as an effective way to leverage public and private joint interests.

[176] Scoles, S., 2020. There Are No Real Rules For Repairing Satellites In Space—Yet. [online] Wired. Available at: <https://www.wired.com/story/there-are-no-real-rules-for-repairing-satellites-in-space-yet/> [Accessed 15 December 2020].

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