

ON-ORBIT SERVICING COMMERCIAL OPPORTUNITIES WITH SECURITY IMPLICATIONS

Abstract	52
Group Participants	53
1. Introduction	54
2. Current State of the Industry	55
3. Working Group Approach	58
3.1. Stakeholder Definitions	58
3.2. Simulation Results	59
4. Recommendations	62
5. References	63

ABSTRACT

The On-Orbit Servicing (OOS) working group discussed legal and political implications of developing a commercial OOS industry. The group considered the benefits that OOS and Active Debris Removal (ADR) can offer the satellite industry, as well as potential disadvantages for international relations between space faring nations.

To gain an accurate perspective of stakeholders involved in such a process, the OOS working group held a mock hearing for OOS licensing, with members of the working group assigned to represent stakeholders. Working group members presented their cases at a simulated domestic regulatory panel, constructed of members representing various government ministers, to fully explore stakeholder views. The mock hearings explored the challenges faced by OOS and ADR entrepreneurs as well as the benefit of regulation. The groups highlighted recommendations to ensure the practicality of OOS and determine how best to encourage licensing and regulation of such activities, as summarised below.

1. The United Nations (UN) should provide regulatory guidelines for OOS and ADR.
2. Government agencies should license OOS. The Federal Aviation Administration (FAA) has taken responsibility for licensing commercial space transportation in the United States and this should be extended to OOS/ADR missions to enable short-term advancement prior to further UN regulation.
3. Government should support OOS and ADR development to ensure continued demand. This includes leading by example on government satellites and potential launch levies to enable on-going ADR funding.
4. All stakeholders should prevent weaponisation of space through transparency of operations.
5. Nations should initiate international cooperation on ADR.

OOS and ADR will ensure sustainable use of satellites, particularly in LEO and GEO, for the coming decades. It is through transparency, economic stimulation and close monitoring that such endeavours will be successful.

GROUP PARTICIPANTS

Name	Nationality	Role
Christopher Johnson Robert Bell	USA USA	Subject Matter Experts
Daniel Rey	Canada	OOS Keynote Speaker
Adam Vigneron	Canada	Moderator
Jacob Hacker* Martin Losekamm* Nikita Sardesai*	Australia Germany Australia	Rapporteurs
Laura Bettiol Daniel Brack Emma Braegen George Calder-Potts Joyeeta Chatterjee Kathleen Coderre Roxanne Côté Bigras Matthew Driedger Caitlin Egen Emilie Froeliger Eren Gorur Weston Hankins Alaa Hussein Ilji Jang Matthew Noyes Lyle Roberts Bruno Sarli Thomas Sinn Anne Wen Eric Wille	Italy Israel Australia UK & South Africa India USA Canada Canada United Kingdom France & USA Australia Mexico United Kingdom South Korea USA Australia Brazil Germany Canada Germany	Group Members

*Main authors of this report.

1. INTRODUCTION

Since the beginning of the Space Age in 1957, artificial satellites have been launched by several countries without much consideration for future activities in space. Objects, ranging from small ejectables to defunct satellites and burned-out upper stages of rockets, were frequently left in orbit. While larger objects such as the upper stages fall back to Earth relatively quickly, a number of dead satellites remain in orbit from the first years of the Space Age. In recent years the problems of space debris have become more widely known, most notably following the test of the Chinese anti-satellite system targeting non-operational Fengyun-1C satellite in 2007 and the collision of the American Iridium 33 and the Russian Cosmos 2251 satellites in 2009. In the case of Fengyun-1C destruction, 90% of the objects created by the explosion are believed to be circling Earth in long-lived orbits, potentially threatening active spacecrafts for years. The Iridium 33 and Cosmos 2251 collision two years later marked the first major impact of two spacecraft in orbit and led to a significant increase of individual debris objects. Although Cosmos had been decommissioned several years earlier, Iridium was operational prior to the catastrophic collision. Experts agree that once debris reaches a critical density, a single collision could lead to a runaway chain reaction, as new debris is created faster than objects are removed by natural or man-made processes. There is no scientific consensus when density for this so-called Kessler syndrome will reach the critical threshold, but it is clear that it would render large portions of the currently populated orbital bands unusable [1].

The combination of increasing space debris and limited orbital slots makes on-orbit servicing (OOS) of satellites both in Low Earth Orbit (LEO) and Geostationary Orbit (GEO) increasingly important. In GEO, the availability of orbital slots is inherently limited, constrained not only by the minimum safety distance between two objects but also by the risk of radio interference. Although LEO orbit availability is not as limited in GEO, many more spacecraft have been placed in orbit. The International Telecommunication Union (ITU) oversees allocation of slots, but in some cases the inter-satellite spacing is well below 100 km. Despite remarkable gains in efficiencies and performance of communication satellites achieved, the demand for new platforms in GEO is expected to continue rising [2], due to rising global demand for wireless communication and increasing utilisation of inter-spacecraft communication for manned and unmanned systems.

OOS of spacecrafts may help avoid overcrowding and the chain reaction of debris creation in both GEO and LEO by several mechanisms. A servicing spacecraft could be used to de-orbit larger pieces of debris, thereby reducing the probability of major future collisions. It may also re-fuel empty satellites that are otherwise functional so that they regain their station-keeping and collision-avoidance capabilities [3]. A third particularly interesting possibility for communication service providers owning expensive high-performance geostationary platforms is the on-orbit repair of defunct satellites. Spacecraft targeted for repair may include newer spacecraft specifically designed to be serviceable, but also older spacecraft already in orbit today. The latter category is not only technically challenging, but may also pose significant problems in developing new legislation.

To identify and analyse the current state of the OOS industry, the working group constructed a simulated regulatory hearing with group members assigned to

represent relevant stakeholders. The hearing was carried out over two hours, where each stakeholder demonstrated the effects of a developed OOS industry on their interests. This provided an interesting opportunity for group members to adopt and further understand the views of different parties. Throughout the simulation, main concerns of the stakeholders were identified [4] and analysed. The report uses these areas of note to provide recommendations on legal and political issues to address during development of the OOS industry.

2. CURRENT INDUSTRY STATE

Industries and agencies have developed capabilities related to OOS for many years, although its utility for ADR has only recently been met with more widespread interest. American and Russian space agencies have carried out operations on multiple targets during the past decades [2] and new technologies now enable the extension of repair and service missions in space. The stakeholders involved in OOS industry are summarised below in Table 1, along with their influence on the industry. The dynamic of this industry is such that there is a conflict of interest between parties as outlined in section 3.1.

2.1 Previous On-Orbit Operations

US Space Transportation System (STS) allowed the first capture of a spacecraft in orbit for service operations. The five servicing missions to the Hubble Space Telescope (HST) are the most famous missions conducted using STS. The choice of HST also stands out, as it was the first telescope specifically designed to allow service and repair by astronauts. Recovery of Palapa B2 and Westar 6 satellites during STS-51-A in 1984 marked the first time artificial objects were actively removed from their orbit and, in this case, brought back to Earth [2].

More recently, assembly of the International Space Station (ISS) would not have been possible without the extensive involvement of astronauts and robotics. Although humans played a vital role in the many of the operations performed, robotic systems such as the Canadarm2 have demonstrated their extensive reliability and versatility required for OOS [5].

2.2 Recent Developments

To address the growing problem of space debris, private organisations and government agencies have devised methods to de-orbit large space objects with the use of spacecraft. Such OOS is an active research area, with most development work performed by or under contract with national space agencies. The lack of research and development by commercial industry is likely due to the uncertain business value.

MacDonald, Dettweiler and Associates Ltd (MDA) announced the first commercial small-scale refuelling mission in cooperation with Intelsat in 2010. The early design paradigm was a GEO fuel-depot satellite to refuel multiple customers' communications satellites. It would also have the capability to move defunct platforms into a graveyard orbit and free expensive GEO slots. The project, however, was put on hold in 2012 after Intelsat dropped out of the collaboration and a new partner could not be found.

NASA has been performing a technology demonstration operation for robotic refuelling aboard the ISS since 2011. During Phase I and II of the Robotic Refuelling Mission (RRM), the station's Canadarm2 and its Dextre telemanipulator successfully performed a series of refuelling tests on hardware that had not been designed for refuelling [3]. Tests with new experimental hardware are continuing.

The German DEOS mission (Deutsche Orbitale Servicing Mission) to be launched in late 2017 and the proposed e.Deorbit mission to de-orbit the inoperative ESA satellite Envisat are two further examples of OOS. Deorbiting Envisat is particularly crucial as this satellite could trigger a self-sustaining chain-reaction of debris creation, should it collide with another object.

These missions are examples of OOS in research and development. While there are currently no operative OOS systems in orbit, the first full-scale servicing platforms will be ready for launch in the coming years. Once the first systems have demonstrated their utility, it is likely that commercial industry will become more involved in OOS.

2.3 Legislation & Policy

Currently, policies concerning use of outer space and liability for operations in orbit are limited to two major documents: the Outer Space Treaty (Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies) [5] and the Convention on International Liability for Damage Caused by Space Objects [6].

Table 1: Stakeholders in the OOS industry

Stakeholder	Description and Details	Interest	Power
Government Space Agencies	Government space agencies such as NASA, ESA and JAXA.	High	High
Military/Defence	Space based military and defence capabilities. Heavy reliance on space assets (GPS, Earth observation satellites, etc.).	High	High
Foreign Affairs	Foreign affairs deal with any issues that arise with other countries, and are interested in ensuring compliance with international law and continued peaceful utilisation of space.	High	Low
Justice	Concerned with legal consequences.	Low	Low
OOS Provider and Customer	Parties involved in providing and receiving servicing.	High	High
UN COPUOS	United Nations Committee on the Peaceful Uses of Outer Space. Official global forum to discuss OOS policy.	High	Low
Launch Industry	Provides launch capabilities to place assets in orbit, but also produce space debris such as discarded rocket bodies.	High	High
Satellite Manufacturers	OOS may reduce total number of new manufactured satellites, but also provides an opportunity to design new OOS vehicles.	High	High
Satellite Operators		Low	Low
Satellite Owners		High	High
Satellite Users	Want the functionality of operational satellites but are not necessarily concerned with how they get it or how that service is maintained.	Low	Low
Space Debris Community	Interested in debris generation and mitigation mechanisms.	High	Low
Insurance Companies	Insurance companies request high insurance premiums for high-risk missions/operations.	High	High
Non-Governmental Agencies	Interested in the continued preservation of the near-Earth space environment.	High	Low
Space-related Research Institutions/Academics	Research institutions are often reliant on the functionality provided by space assets. They are also interested in the continued use of the space environment such as Earth observing satellites.	High	Low
General Public	The general public use satellite derivative services and have an inferred interest in their continuance.	Low	Low

3. WORKING GROUP APPROACH

To arrive at appropriate and constructive recommendations to develop OOS industry, the working group constructed a mock regulatory hearing with the major stakeholders. This procedure allowed the group to assess current industry status from varying points of view to further understand the implications of proposed regulation developments.

3.1 Stakeholder Definitions

Working group members were designated representatives of companies and customers with appropriate economic leverage while others represented government roles typically required for space-faring nations. The major stakeholders considered in the mock regulator, hearings are summarised below.

OOS Service Provider: Executive members of CanadaGOOS (Canadian Group for On Orbit Servicing) own intellectual property for Canadarm and have access to a modular spacecraft bus and space-plane platform. The priorities of the service provider are to demonstrate a successful business case whilst meeting the requirements of the regulators as well as local and foreign militaries.

OOS Customer: Executive members of EuroSat, a dominant telecommunications satellite service provider for Europe, Asia and the Pacific, launches an abundance (4-7 units per year) of geosynchronous satellites. The OOS customer seeks economic benefits through extending lifetime of future satellites and upgrading existing satellite units. The customers has reservations and concerns that the Service Provider might provide services to competing companies using capacities derived from the investment of EuroSat.

Prospective Investor: An individual has the monetary capability to invest 1-2 billion US dollars into the OOS industry. The investor's main priorities include a significant return on investment and a successful business case. To ensure this, the prospective investor is keen to see innovation in the industry without restrictive governmental oversight; a clear and simple regulatory environment is desirable.

Domestic Regulators: The intergovernmental panel consists of members from the Foreign Ministry, the Executive Office of Science and Technology Policy and the Ministry of Aviation. The domestic military liaison will also be consulted. The concerns of each panellist making up the domestic regulators are as follows:

- Foreign ministry: to ensure compliance with international law and assure partners/allies of the continual peaceful uses of outer space.
- Executive Office of Science and Technology Policy: to set domestic policy and regulation under the appropriate economic and legal posture and to ensure that innovation in the industry is fostered for economic growth. The commercial feasibility of new space ventures must be promoted.
- Ministry of Aviation: to license and oversee OOS without discouraging innovation. The regulatory power of this body will be extended to include on-orbit operations.

Domestic Military Liaison: Highly ranked military officials with responsibility in classified reconnaissance and Earth observation areas are concerned with controlling land, air, sea and space. Its main concerns lie in the potentially hostile capabilities of servicing modules, as this is an avenue to weaponisation of space.

Allied Country Delegation: Foreign Ministry of an allied state is seeking to licence and regulate OOS, with capabilities to open an international market.

Non-allied Country Delegation (with military attaché): The permanent delegation member of the United Nations from a non-allied country is mainly concerned about the possible hostile capabilities of OOS units and potential interference with spy satellites. The launch of an OOS unit could be viewed as a declaration of war.

3.2 Regulator Hearing Simulation Results

Each stakeholder made position statements prior to simulated regulator hearings. The main proposals and issues relating to each of the stakeholders are summarised as follows.

3.2.1 OOS Service Provider

An estimated 200 satellites will require servicing by 2020 [1]. OOS is an economically viable space venture that provides a commercial opportunity, particularly when accounting for graveyard orbit operations. The majority of technological capabilities required for such missions already exists with the remainder feasible in the short- to mid-term.

Challenges: Key legal and political concerns for the service provider are centred on mission performance and success, and potential asset damage of units registered to other launching states. The Outer Space Treaty (OST 1967) [7] and the Liability Convention (LIAB 1972) [6] cover liability of space operations extensively. Article VI of OST allocates responsibility to the launching state, whilst Article VII OST establishes liability of the launching state for damages to an "object or its component parts on the Earth, in air space or in outer space, including the Moon and other celestial bodies" as elaborated in articles II and III LIAB. Liability from debris generated as a result of OOS missions could be inferred by an extension of these documents. This has been broken down into a simple question and a potential strategy for removing any ambiguity that exists in current literature.

Question: Who is liable for future damage caused by mission related debris resulting from OOS missions and over what time frame is this liability maintained?

Strategy: The launching state shall remain wholly liable for any future damage caused by debris generated as a result of OOS missions in perpetuity.

An additional concern is the potential for OOS capabilities to be used for military/defence purposes, surveillance or corporate espionage. This would likely result in standards and regulations being consolidated, potentially reducing the commercial viability of the technology. Any policy that is derived from these concerns should not negatively impact the commercial viability of OOS.

Policy concerning the military/defence application of OOS might include extensions to existing security protocols to ensure that proximity operations, where an OOS satellite comes within 25 km of another launching state's asset, are fully transparent. One strategy is to publicly announce proposed mission profiles, allowing foreign states opportunity to raise any concerns. This is particularly important when it comes to potential proximity of the OOS satellite with 'unregistered' satellites.

3.2.2 OOS Customer

Challenges: The majority of the customer's policy-related concerns arise from the lack of regulations. The customer would like to comply with the respective government's security rules in order to have its satellites serviced. If the security policy created were too onerous, however, the mission costs would increase and reduce the customer's financial gain.

Benefits of regulation: The potential OOS customer will most likely pressure policy-makers to create regulations. As a result, the customer will be willing to comply or consider another state for launch. Without regulation, the customer would hesitate to sign contracts for OOS missions.

3.2.3 Prospective Investors

Challenges: Investors and sources of private funding for OOS are concerned not only with the success of the mission but also the commercial value of the service. The amount of freedom and degree of self-regulation are of high importance for the ability of an OOS company to be commercially viable and competitive. Financial supporters hold considerable leverage in a company at a national and international level. As a result, this leverage can be utilised to establish security and influence the design of a working industry. Despite the obvious challenges, this will be beneficial to the industry.

Benefits of regulation: To initiate international discussion, countries should compile a set of goals and requirements to enable a successful and sustainable agreement. These should be used as criteria when developing the policy that will guide the future OOS industry. A combination of private and public funding is likely important to ensure the on-going success of the industry. Potential funding streams include launch levies that would contribute to on-going ADR and OOS as well as the licensing of satellite spots, particularly in GEO.

3.2.4 Domestic Regulators

Challenges: The regulatory committee must determine the assignment of liability, both for mission success and long-term damages. Although launching states bear ultimate responsibility for damage to national and international space assets during OOS, it is not economically feasible for governments to cover all liability for commercial activities, particularly in the short term. In addition, regulatory bodies must have adequate access to proprietary servicer and provider component and procedural specifications to guarantee minimal safety requirements are met, as both the servicing vehicle and the vehicle being serviced must be assessed for risks in the event of mission failure. Finally, the domestic regulators must ensure security of communications and ground control, particularly the confidentiality of information, and prevent the weaponisation of space.

Benefits of regulation: To satisfy these regulatory issues, OOS missions should be covered by mandatory private insurance. Insurance requirements may be partitioned into short-term based on mission success and long-term damage liability to third-party space assets or contamination of orbital sectors caused by space debris. The long-term insurance may not be cheaper but is required for a minimum number of years to mitigate costs to the launching state. To obtain proprietary information without discouraging private sector involvement, a trusted third party bound by non-disclosure agreements could verify compliance during safety reviews.

3.2.5 Domestic Military Liaison

Challenges: The domestic military liaison shares many views with domestic regulators, although security is a more pressing concern. Countries and commercial operators prioritise the security and confidentiality of their assets in space, making any collaboration with other entities for servicing or debris removal challenging. Both

satellites undergoing servicing and satellites in close proximity to those being serviced are at risk for having proprietary information inadvertently exposed.

With the capability to control or destroy other satellites, OOS has great potential to be utilised as a space weapon. If misused, OOS could lead to a lack of trust and a potential arms race in space. System security is required to prevent misuse, but 'military only' control could lead to suspicion and is unlikely to be cost effective. On the other hand, increased transparency or poorly managed commercial companies could enable others to exploit vulnerabilities or expose technology and security information. Securing the homeland and proprietary information is of utmost importance.

Benefits of regulation: Despite being an economically beneficial endeavour, OOS has the potential to be hazardous. Various entities will almost certainly attempt to develop weaponisation capabilities of units, even if prevention programs are in place. The government requires strong regulations to reduce this risk and ensure national security. Many of these considerations involve other nations, so risks must be managed to maintain sound foreign relations. Preventing weaponisation of space is crucial to allow easy access and sustainability of essential services.

3.2.6 Allied Country Delegation

Challenges: Allied countries generally support development of OOS regulations and recognise that an over-zealous military could restrict technological developments. Since the development of OOS capabilities may also enhance trade relations and technology sharing, allied countries should address trade embargoes and restrictions on import/export related material to maximise access for appropriate parties. The potential weaponisation of space and the lack of clarity surrounding liability sharing of spacecraft/launch vehicle are concerns that must be addressed prior to any action. For this reason, regulation must be developed such that the industry is monitored but not restricted.

Benefits of Regulation: Orbit manipulation by another entity has the potential to damage third party satellites. Results from such actions may cripple other nations, particularly following damage to economically critical GEO assets.

Regulation will set precedent and establish custom that carries weight in international law. Furthermore, establishing a forum to notify interested parties and discuss OOS in a proactive manner would greatly benefit allied countries.

3.2.7 Non-allied Country Delegation (with military attaché)

Challenges: Non-allied country delegations are concerned with weaponisation of space due to new capabilities of launched OOS units. Addressing security concerns surrounding the mission, such as how to prevent hacking or hostile takeover, are of utmost importance.

Benefits of Regulation: Due to the security concerns surrounding ADR and OOS capabilities amongst foreign delegations, transparency is required to ensure mission success and to aid communication with non-allied countries. Regulating these missions would increase cooperation and aid in the mitigation of potential weaponisation.

4. RECOMMENDATIONS

The development of an OOS industry is both technologically and economically viable. Servicing hardware in orbit will reduce space debris and mission cost as units become optimised for servicing. OOS of current satellites will either increase mission life or clear orbits for new missions. Additionally, maturation of the industry will encourage development in robotics and autonomous systems. The major stakeholders outlined all demonstrate conflicts of interest concerning the industry, and so establishment of a regulatory body to monitor future orbital activities is required. This body could also work to satisfy the need for transparency and confidence building between nations to ensure a secure industry. Based on the results of the simulated hearing the working group makes the following recommendations:

1. **Extension of Outer Space Treaty.** Currently, the country from which a spacecraft is launched bears ultimate responsibility and liability for the asset placed in orbit. In scenarios where objects are built in one country, launched by another country and serviced by a third country, the liability for damage inflicted on the serviced object itself or assets owned other parties may need to be reassigned. The group recommends that UNCOPUOS discuss OOS and ADR regulations with the outlook to develop working guidelines to be ratified by nations participating in OOS activities, including customers and providers.
2. **Government Agency Role extended to monitoring and licensing OOS and ADR activities.** UN regulation of ADR and OOS activities is likely to be a complex and long-term requirement. The working group recommends that national agencies, such as the Federal Aviation Administration (FAA) in the United States, be expanded to regulate and monitor such activities to maintain government relations and manage liability. Bodies such as the FAA have proven to be efficient in similar endeavours such as the regulation of commercial space transportation.
3. **Governmental support of OOS/ADR industry.** The conflict of interest and lack of current demand for OOS services renders support and funding by government institutions crucial for the development of the OOS industry. By creating demand for services, the government can provide the initial foundation of the industry and keep investors interested in the business. Governments may conduct technology demonstrator missions through supporting national space agencies, commissioning service missions for military or other governmental spacecraft and implementing additional launch levies to contribute to future ADR.
4. **Prevent weaponisation of space.** OOS clearly creates new possibilities for the weaponisation of space. Confidence in OOS must be established by demanding sufficient transparency of all operations. As this contrasts the confidentiality requirements of certain governmental missions, solutions to provide transparency whilst keeping military secrecy uncompromised should be discussed on an international level.
5. **Initiate global debris removal initiative.** To prevent runaway debris creation and create demand for OOS services, the working group recommends initiating a global project to remove defunct and unused objects from orbit as a potential UN-

led initiative. As there is currently no urgent demand for debris removal missions from the commercial industry, projects are not likely to be initiated until it is more economically viable. Considering the current extent of debris, the possibility of the situation seriously worsening to the critical threshold cannot be ruled out.

6. **Initiate regulations for active debris removal.** Regulations to remove or prevent the creation of space debris are currently limited to non-binding documents such as the UN Space Debris Mitigation Guidelines. The working group recommends extension of existing guidelines and discussion of options to introduce fees for occupying orbital slots in both GEO and LEO. This would not only create demand for ADR services, but would also make the extension of spacecraft operations more economically viable.

5. REFERENCES

1. National Aeronautics and Space Administration, Goddard Space Flight Center, "On-orbit satellite servicing study." Project Report, October 2010.
2. Tortora, J.J., "Space Trends 1986 - 2011," May 2012.
3. D. Leone, "NASA Ready To Put Robotic Refuelling to the Test," in Space News, August 11 2014. url: <http://www.spacenews.com/article/civil-space/41556nasa-ready-to-put-robotic-refuelling-to-the-test>
4. A. Krolkowski and E. David, "Commercial on-orbit satellite servicing: National and international policy considerations raised by industry proposals," *New Space*, vol. 1, no. 1, 2013.
5. B. Weeden, Secure World Foundation, *International Perspectives on Rendezvous and Proximity Operations in Space and Space Sustainability*, February 2014. Presented at the United Nations Committee on the Peaceful Uses of Outer Space, Scientific and Technical Subcommittee.
6. United Nations Office for Outer Space Affairs, "Convention on International Liability for Damage Caused by Space Objects," no. 961 U.N.T.S. 187, 1972.
7. United Nations Office for Disarmament Affairs, *United Nations Treaties and Principles on Outer Space*. No. 610 U.N.T.S. 205, United Nations Publication, October 2002. Text of treaties and principles governing the activities of States in the exploration and use of outer space, adopted by the United Nations General Assembly.