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Abstract

The On-Orbit Servicing (OOS) working group discussed the legal and political implications of the development of the on-orbit servicing industry. The group considered the benefits which OOS and Active Debris Removal (ADR) pose for the satellite industry as well as the potential disadvantages for international relations between space faring nations.

To gain an accurate perspective of all of the stakeholders involved in such a process, a simulation hearing for OOS licensing was established. Members of the working group were assigned as a variety of stakeholders who were required to present their case to a domestic regulatory panel constructed of various government ministers. Based on the hearing, the challenges faced by such endeavours as well as the benefits of regulation were highlighted, resulting in a number of recommendations outlining how to ensure practicality of OOS and how to encourage the licensing and regulation of such activities. These are summarised as:

1. UN regulation for OOS and ADR
2. Government agency in licensing OOS. The FAA has taken responsibility for licensing Commercial Space Transportation in the US and this example should be extended to OOS/ADR missions to enable the advancement in the short term prior to further UN regulation
3. Government support of OOS and ADR to create continued demand. Includes leading by example on government satellites and potential launch levies to enable ongoing ADR funding
4. Prevent weaponisation of space through transparency of operations
5. Initiate international cooperation on active debris removal

On-Orbit Servicing and Active Debris Removal 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.

Contents

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1 Introduction

On-orbit servicing of satellites both in Low Earth Orbit (LEO) as well as in Geostationary Orbit (GEO) will become increasingly important in the upcoming decades. In GEO, the availability of orbital slots is inherently limited, constrained not only by the minimum safety distance between two objects, but also because of possible radio interferences. The allocation of slots is overseen by the International Telecommunications Union (ITU), but in some cases the inter-satellite spacing is already well below 100 km. Although remarkable gains in efficiencies and performances of communication satellites have been achieved in the past decades, it is expected that the demand for new platforms in GEO will continue to rise. [1] This is not only due to the rising global demand of wireless communication, but also because of the increasing utilization of inter-spacecraft communication for both manned and unmanned systems.

Although in LEO the availability of orbits is not as limited as in GEO, many more spacecraft have been placed in orbit. 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. Oftentimes many objects were left in orbit, ranging from small ejectables to defunct satellites and burned-out upper stages of rockets. While the latter generally fall back to Earth relatively quickly, there still are a number of dead satellites in orbit from the first years of the Space Age. Only in recent years has the topic of space debris come to more widespread awareness, most notably through the test of the Chinese anti-satellite system targeting the non-operational Fengyun-1C satellite in 2007 and the 2009 collision of the American Iridium 33 and the Russian Cosmos 2251 satellites. While the latter was already decommissioned several years before, Iridium 33 was still operational at that time. It was the first major collision of two spacecraft in orbit and lead to a significant increase of individual debris objects. In the case of Fengyun-1C, 90% of the objects created by the explosion are believed to be circling Earth in long-lived orbits, potentially threatening active spacecrafts for years. It is widely assumed that once a critical density of objects is reached, a single collision can lead to a runaway chain reaction, as new debris is created faster than objects can be removed by both natural and man-made processes. Although there is no consensus in the scientific community when the critical density for this so-called Kessler syndrome will be reached, it is mostly undisputed that it would render large portions of the currently populated orbital bands unusable [2].

On-orbit servicing (OOS) of spacecrafts may help to avoid overcrowding and a chain reaction of debris creation in both GEO and LEO in several ways. 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 satellites that ran out of fuel but are otherwise functional, so that they regain their station-keeping and collision-avoidance capabilities [3]. A third possibility particularly interesting 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 in particular 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 where group members were assigned to 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 process of the simulation, the main concerns of the stakeholders were noted [4] and analysed; these are used in this report to provide recommendations on legal and political issues to address within the development of the OOS industry.

2 Current Industry State

Although it has only recently come to more widespread attention, the capability of On-Orbit Servicing has been existing for many years. Multiple operations on several targets have been carried out by both the American and Russian space agencies during the past decades [2]. New technologies now enable the extension of repair and service missions in space. The stakeholders involved in the OOS industry are summarised in table 1 below, along with their influence on the industry. The dynamic of the industry is such that there is a conflict of interest between parties; as outlined in section 3.1, this was discussed in detail by the working group.

2.1 Previous On-Orbit Operations

The US Space Transportation System (STS) for the first time allowed the capture of spacecraft in orbit for service operations. The five servicing missions to the Hubble Space Telescope (HST) are the most famous missions conducted using the STS, although others have been performed as well. The HST was the first telescope specifically designed to be serviced by astronauts. The recovery of the 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, the 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, it has become increasingly clear in the past few years that robotic systems such as the Canadarm2 are very reliable and versatile tools that can be extensively used for OOS [5].

2.2 New Developments

New research is being conducted in all areas of On-Orbit Servicing. Most development work is currently done by or under contract of national space agencies, probably because the commercial industry has not yet identified its business value. MDA (MacDonald, Dettweiler and Associates Ltd.) announced the first commercial small-scale refuelling mission in cooperation with Intelsat in 2010. The early design foresaw a fuel-depot satellite launched into GEO that would be able to refuel several of the customer's communications satellites. It would also have the capability to move defunct platforms into a graveyard orbit, thus cleaning up expensive GEO slots. However, the project was put on hold in 2012 after Intelsat dropped out of the collaboration and a new customer could not be found.

NASA has been performing a technology demonstration operation for robotic refuelling aboard the ISS since 2011. During phase I and phase II of the Robotic Refuelling Mission (RRM) the station's Canadarm2 and its Dextre telemanipulator were successfully used to perform a series of refuelling tests on hardware that had not been designed for refueling [3]. It is planned to continue the tests with new experiment hardware.

To address the growing problem of space debris, private and governmental organisations have devised methods to de-orbit large space object with the use of spacecraft. 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 only two examples. Envisat itself is particularly interesting, in that it could possibly be the trigger for a self-sustaining chain-reaction of debris creation should it collide with another object.

While these missions are only examples of currently performed R&D in field of OOS, it becomes clear that although there currently is no operative OOS system in orbit the first full-scale servicing platforms will be ready to be launched in a few years. As soon as the first systems have been proven to work it is likely that the commercial industry will start to get more involved in the OOS business.

2.3 Legislation & Policy

Currently, policies concerning the use of outer space and the 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) [6] and the Convention on International Liability for Damage Caused by Space Objects [7].

Table 1: Stakeholders in the OOS industry

Stakeholder	Details	Interest	Power
Government Space Agencies	Government funded agencies such as NASA, ESA, JAXA, ESA etc.	High	High
Military/Defence	Space based military and defence capabilities; countries with heavy reliance on space assets (GPS, Earth observation satellites, etc.)	High	High
Foreign Affairs	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 the providing and receiving servicing	High	High
UN COPUOS	Official global forum to discuss OOS legislation and policy	High	Low
Launch Industry	Provides launch capabilities to place assets in orbit; also producing space debris (discarded rocket bodies, etc.)	High	High
Satellite Manufacturers	Companies that built space vehicles; may be limited by OOS policies	High	High
Satellite Operators		Low	Low
Satellite Owners		High	High
Satellite Users/General Public	Desire operational satellite functionality however are less concerned with legislation procedures	Low	Low
Space Debris Community	Interested in debris generation and mitigation mechanisms	High	Low
Insurance Companies	Companies concerned with mission success	High	High
Non-Governmental Agencies	Interested in the continued preservation and technological development of the near-Earth space environment	High	Low
Research Institutions/Academics	Research institutions are often reliant on the functionality provided by space assets; also interested in the continued use of the space environment (e.g. Earth observing satellites)	High	Low

3 Working Group Approach

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

3.1 Stakeholder Definitions

The major stakeholders considered are summarised below. Some were designated as companies with appropriate economic leverage while others were given government roles typically filled within space-faring nations.

OOS Service Provider: Executive members of CanadaGOOS (Canadian Group for On Orbit Servicing) owning intellectual property for *Canadarm* and access to a modular spacecraft bus and spaceplane platform. The priorities of the service provider are to demonstrate a successful business case whilst meeting the requirements of the regulators, and both the local and foreign military.

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

Prospective Investors: Individual with the monetary capability to invest 1-2 billion USD into the OOS industry. Main priorities include a significant return 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: An intergovernmental panel consisting of members from of 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 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: setting the 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: the regulatory power of this body will be extended to include on-orbit operations; tasked with licensing and oversight whilst being careful to encourage innovation

Domestic Military Liaison: Highly ranked military officials with repsonsibility in the classified reconnaissance and Earth observation areas - concerned with controlling to the fourth dimension (land, air, sea and space). Main concerns lie in the hostile capabilities of servicing modules as this is an avenue to the weaponisation of space.

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

Non-allied Country Delegation (with military attaché): Permanent delegation member of the United Nations from a non-allied country. Main concerns are with the possible hostile capabilities of the OOS units and potential interference with spy satellites; possibly viewing the launch of a unit as a declaration of war.

3.2 Simulation Results

Prior to the simulation, statements were taken from each stakeholder. The hearing preceedings were also recorded; the main proposals and issues relating to each of the stakeholders are summarised as follows.

3.2.1 OOS Service Provider

It is estimated that roughly 200 satellites will required servicing by the year 2020 [2]; this provides a commercial opportunity and ensures an economically viable space venture, particularly when accounting for graveyard orbit operations. The majority of the technological capability 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 the mission performance and success and the asset damage of units registered to other launching states. The Outer Space Treaty (OST 1967) [6] and the Liability Convention (LIAB 1972) [7] cover liability of space operations extensively. Article VI OST allocates responsibility to the launching stage, whilst Article VII OST establishes liability of the 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.

The extension on this is the concern of liability from debris generated as a result of OOS missions. 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, corporate espionage, etc.). 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 the OOS satellite comes within 25 km of another launching state's asset) are fully transparent. One strategy is to publicly announce proposed mission profiles to provide foreign states with the opportunity to raise their 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 policy related concerns from the customer arise from the lack of regulations. The customer will most likely comply with the respective government's security rules in order have its satellites serviced. However, if the security policy created is too onerous, the mission cost would increase and therefore reduce the customer's financial gain.

Benefits of regulation: The potential servicing customer will most likely pressure policy-makers to create regulations. As a result the customer will be willing to comply or consider another state to launch from. Without regulation, the customer can only plan and would hesitate in drawing up contracts to schedule servicing 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 with the commercial value in the service. The amount of freedom and degree of self regulation are of high importance to the ability of an OOS company to be commercially viable and competitive. Financial supporters hold considerable leverage on 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 to regulation: In order to commence international discussions, countries should compile a set of goals and requirements to enable a successful and sustainable agreement. These should be used as a set of criteria when designing the policy that will define the future OOS industry. It is suspected that a combination of private and public funding is important to ensure the ongoing success of the industry. Potential funding streams include launch levies which would contribute to ongoing 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 (both the servicing vehicle and the vehicle being serviced must be assessed for risks in the event of mission failure). Furthermore, the domestic regulators are concerned with the security of communications and ground control, particularly the confidentiality of information. They also seek to ensure the non-weaponisation of space.

Benefits to regulation: To satisfy these regulatory issues, it is recommended to have mandatory private insurance for OOS missions. Insurance requirements may be partitioned by short-term (mission success) and long-term (damage liability to third-party space assets or contamination of orbital sectors caused by space debris), the latter of which may be cheaper but is required for a minimum number of years to mitigate costs to the launching state. To obtain proprietary information for safety reviews without discouraging private sector involvement, the delegation of safety verification to trusted third-parties bound by NDAs as jointly agreed upon by relevant regulatory and private stakeholders is also recommended.

3.2.5 Domestic Military Liaison:

Challenges: The domestic military liaison shared many views with the domestic regulators, however the liaison was more concerned with security issues. Countries and commercial space operators prioritise the security and confidentiality of their assets in space, making any collaboration with other entities for servicing or debris removal challenging. Additionally the issue was raised of servicing tools exposing proprietary information when in close proximity to other satellites in orbit. On orbit servicing has high potential to be utilised as a space weapon, with the capability to control or destroy other satellites. If misused, this is likely to lead to a lack of trust and a potential arms race in space. Security of the system to prevent misuse is required; however 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 to regulation: Whilst OOS can provide economically beneficial endeavours, it can also be hazardous. The weaponisation capability of units will almost certainly be developed by various countries even if prevented locally, thus the government needs strong regulations to reduce this risk and ensure national security. Many of the considerations here involve other nations, therefore these risks needs to be managed to ensure sound foreign relations are maintained. Weaponisation of space needs to be prevented to allow easy access and sustainability of essential services.

3.2.6 Allied Country Delegation

Challenges: Allied countries are mostly in support of the development of OOS regulations and recognise that an over-zealous military could restrict technological developments. The development of OOS capabilities also has the chance to enhance trade relations and technology sharing; therefore, there needs to be an effort to address trade embargoes and restrictions on import/export of related materiel to maximise access for appropriate parties. The potential weaponisation of space and the lack of clarity surrounding the sharing of liability of the craft/launch vehicle are concerns that must be addressed prior to any action. For this reason, regulation must be set so that the industry is monitored but not restricted.

Benefits of Regulation There are economically critical GEO assets in orbit, so when orbits start being manipulated by third parties there is an implication of damage to other third party satellites that may "cripple" another nation. Regulating first will set precedent and establish custom which carries weight in international law. Furthermore, the establishment of a forum to notify and discuss with interested parties in a proactive manner would be highly beneficial.

3.2.7 Non-allied Country Delegation (with military attaché):

Challenges: The issues surrounding on orbit servicing for concerned parties centre around the fear of instigating the weaponisation of space due to the capability of launched units. This raises the question: how can the operator ensure that a servicing instrument does not become a weapon considering the numerous security concerns surrounding such a mission (including hacking, hostile takeover etc).

Benefits to Regulation: Due to the controversy 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 the OOS industry is both technologically and economically viable, as seen from the simulation hearing. Servicing hardware in orbit will reduce space debris and also mission cost, as units become optimised for servicing. Operating on current satellites will either increase mission life or clear orbits for new missions. Additionally, the development of the industry will encourage developments in robotics and autonomous systems. The major stakeholders outlined all demonstrate conflicts of interest concerning the industry, thus it is essential for a regulatory body to be put into operation to regulate future orbital activities. 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 the spacecraft is launched is ultimately responsible and liable for the asset placed in space. In scenarios where objects might be 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 other assets of yet other parties may need to be reassigned. It is recommended that OOS and ADR regulation is further discussed by UNCOPUOS 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/licensing OOS and ADR activities. UN regulation of ADR and OOS activities is likely to be complex and long term. It is recommended that national agencies such as the Federal Aviation Administration (FAA) in the United States be extended to regulate and monitor such activities to ensure maintenance of government relations and management of liability. Bodies such as the FAA have proved to be efficient in similar endeavours such as the regulation of Commercial Space Transportation.

(3) Governmental support of OOS/ADR industry. The aforementioned conflict of interest and the lack of obvious demand for OOS services renders support and funding by governmental 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. This may be done by conducting technology demonstrator missions through national space agencies, through commissioning service missions for military or other governmental spacecraft, and through the implementation of additional launch levies to contribute to eventual ADR.

(4) Prevent weaponisation of space. On-orbit servicing clearly creates new possibilities for the weaponisation of space. Confidence in OOS needs to be established by demanding sufficient transparency of all operations. As this stands in contrast to 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 to 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 stemming 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 a serious worsening of the situation before that point cannot be ruled out right now.

(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 to extend the existing guidelines and to discuss 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.

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