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INTERNATIONAL PERSPECTIVES ON ON-ORBIT SATELLITE SERVICING AND ACTIVE DEBRIS REMOVAL AND RECOMMENDATIONS FOR A SUSTAINABLE PATH FORWARD

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ABSTRACT

On-orbit satellite servicing (OOS) and active debris removal (ADR) are part of an emerging category of future on-orbit activities that are critical for taking the next leap in our use of Earth orbit. The ability to repair or refuel satellites, construct new satellites in orbit, and even remove orbital debris can help drive innovative uses of space and create new possibilities. These activities also raise a host of security, legal, safety, operational, and policy challenges that need to be tackled for this future to be possible.

In 2012 and 2013, Secure World Foundation (SWF) worked with partners to hold a series of conferences, workshops, and panel discussions to explore these various multidisciplinary challenges. The events took place in the United States, Belgium, and Singapore and included representation from a variety of international stakeholders. This paper summarizes those events, provides an overview of key discussion points, and presents significant findings and recommendations. It concludes with steps that industry, governments, and other stakeholders can take to help ensure that future ADR and OOS activities can take place in a safe and secure manner and contribute positively to the long-term sustainable use of space.

I. RENDEZVOUS AND PROXIMITY OPERATIONS IN SPACE AND THEIR ROLE IN SPACE SUSTAINABILITY

Rendezvous and proximity operations (RPO) in Earth orbit are not a new concept. Dozens of RPO activities have performed as part of human spaceflight activities by the United States, Russia, and China over the last sixty years. These activities include several Apollo missions, visits to the American Skylab and Russian Salyut space stations, assembly of the Russian Mir and International Space Stations, and most recently the Chinese visit to their Tiangong-1 space laboratory [1].

Over the last decade, these classical RPO activities have been joined by an emerging category of new RPO activities not related to human spaceflight. One example of these new RPO activities include the U.S. military's Experimental Satellite System 11 (XSS-11), which rendezvoused with multiple U.S. satellites as part of a demonstration of on-orbit inspection capabilities [2]. A second example is the Swedish PRISMA mission which used two microsatellites to demonstrate autonomous rendezvous, proximity operations, and formation flying [3]. A third example is the Chinese SJ-12 satellite, which in August 2010 rendezvoused with anther Chinese satellite in low Earth orbit (LEO) [4].

In addition to these on-going RPO activities, still more are envisioned to be taking place in the near future as part of active debris removal (ADR) and on-orbit satellite servicing (OOS) activities. Over the last several decades, there has been significant growth in the amount of space debris in certain regions of Earth orbit. The threat this space debris poses to active satellites has prompted many in the scientific community to conclude that ADR will be required to ensure the long-term sustainability of space activities [5]. While there are some ADR concepts that do not involve RPO, several of the most technologically advanced and cost-effective techniques do involve RPO.

OOS has been a topic of discussion in the space community for more than a decade and is currently seeing renewed interest [6]. This renewed interest is being driven by advances in technology, particularly miniaturization and automation, as well as increased interest in OOS capabilities by both the commercial sector and governments. These capabilities include the potential ability to diagnose and fix malfunctions in orbit and refuel or extend the life of important satellites [7]. At least one project aims to use RPO to recycle parts from dead satellites into new satellites [8].

Taken together, the more recent and planned future RPO activities are distinct from the historical RPO activities in three main ways. First, these new activities involve two unmanned spacecraft. Second, they are occurring in regions of Earth orbit higher than the traditional human spaceflight zone below 500 kilometers in altitude. Third, they involve private sector actors instead of only governments.

As a result, these ongoing and proposed future RPO in Earth orbit pose a number of unique legal and policy challenges. Some of these challenges arise from the fact that these new and emerging RPO activities are being planned by private sector actors. While not fundamentally different from RPO undertaken by governments in the past, States will need to consider how to provide ongoing oversight of these activities as required by the 1967 Outer Space Treaty.

RPO that involve more than one private actor, more than one State actor, or a mix of private and State actors raise new question about issues of liability, contracts, and responsibility. From a safety standpoint, RPO undertaken in an irresponsible manner could result in accidents or mishaps that damage satellites or create large amounts of space debris. From a security standpoint, certain types of RPO undertaken without sufficient transparency could create misperceptions or mistrust that heighten tensions between States and lead to strategic instability.

Previous research on these challenges has focused on high-level policy issues and choices faced by States and private sector actors for commercial OOS. [9] To build on this research, SWF organized a series of international events in 2012 and 2013 that brought together stakeholders from the private sector, government agencies, academia and civil society to discuss the legal and policy challenges with RPO.

The goal of this series of events was to broaden the discussion beyond just the commercial activities and include perspectives from a wide range of stakeholders. The discussions also involved many in both industry and government who are engaged on these issues and examining ways to address the legal and policy challenges.

This paper summarizes the series of international events and the highlights of the discussions that took place. It begins with a summary of a conference and workshop held by the U.S. Defense Advanced Research Projects Agency (DARPA) in Washington, DC which SWF participated in. The paper then summarizes the follow-on events that SWF organized in Washington, DC, Brussels, Belgium, and Singapore. This paper concludes with a number of main points from the discussions and suggestions for next steps to continue the dialogue and help develop solutions to the policy and legal challenges posed by future RPO, ADR, and OOS activities.

II. SUMMARY OF RECENT RPO EVENTS

A. Washington, DC

Washington Conference on "Fostering Sustainable Satellite Servicing"

DARPA held two events in Washington, DC, on RPO issues. The first event was a conference titled "Fostering Sustainable Satellite Servicing," on June 26, 2012, which was an open and public forum where speakers outlined various concepts and thoughts on legal, policy and regulatory issues associated with OOS. The second day was a closed, invitation-only workshop which went into more detail on some of the issues raised during the first day's discussions. SWF participated in both events.

The conference's first day opened with a welcome from Mr. David Barnhart of DARPA. He spoke about DARPA's Phoenix program, which is developing the technology for recycling parts of dead spacecraft in geostationary orbit (GEO) by using a robotic arm on a spacecraft that could use salvageable communications components off of dead satellites to put together to make new, smaller "sat-lets." Given the technologies and on-orbit operations required to make this program a success, DARPA wanted to have an international dialogue in order to increase transparency about their intent and to raise awareness about OOS and RPO efforts. Then Mr. Bill Mackey of the Canadian Space Agency talked about the United Nations Committee on Peaceful Uses of Outer Space (COPUOS)'s Long-Terms Sustainability of Outer Space Activities (LTSSA) Working Group, saying that OOS and ADR will be necessary and even required topics to be discussed by the working group. He gave Canada's position of fully supporting the commercialization of OOS, and discussed "alternative use concerns" about OOS, saying that transparency and confidence-building measures (TCBMs) will apply to satellite servicing and that it is important now to establish best practices to avoid this concern.

Next was the opening session, titled a "Sampling of Activities and Projects," which had eight speakers talking about OOS projects that their organizations have worked on in the past or are planning on doing in the future. Mr. Bryan McGuirk of ViviSat discussed their Mission Extension Vehicle (MEV), which he said could help clean up the GEO arc, rescue satellites, and so forth. Dr. Juergen Drescher of DLR presented DLR's orbital servicing mission, DEOS. Mr. Manny Leinz of Boeing gave a presentation on Orbital Express, which involved autonomous RPO and capture. Mr. Ben Reed from NASA's Satellite Servicing Capabilities Office discussed what many call the five R's of servicing: remote survey; relocation; refueling; repair; and replace orbital replacement unit (ORU). Finally, JAXA's Mr. Mitsushige Oda asked the interesting question: what is the value of an old satellite? To make it more personally relevant to the audience, he asked, do you buy a 15-year-old car or a new one, and when you're thinking of buying a used car, how old a one are you willing to buy?

The next panel session discussed policy and legal issues of OOS and ADR. Wing Commander Duncan Blake of the Royal Australian Air Force focused on the legal issues of servicing hosted payloads or spacecraft with hosted payloads. He identified three stages, all of which have their own unique legal issues: preparing for a servicing mission, during a servicing mission, and after the conclusion of a servicing mission. Ms. Joanne Gabrynowicz of the

University of Mississippi School of Law talked about space as a commons, which she said ensures that all entities have a nonexclusive right to use and explore it. Servicing can be thought of a "use" of space. Beyond this concept, the legal framework relevant to servicing is Article IX of the 1967 Outer Space Treaty, which requires "due regard." She stressed the need for this concept to be elaborated upon if servicing is to become a reality. She emphasized the importance of the Registration Convention, insurance, and addressing intellectual property concerns for any future servicing scheme. Gabrynowicz also believed that international participation or cooperation would be necessary for satellite servicing, which will require transparency.

Dr. Ram Jakhu of McGill University spoke of the need for a reliable market and minimal risk if satellite servicing is to ever become a reality. He posited that the international community must define a space object and address the perception of OOS; furthermore, he felt that there is a need for the establishment of some sort of international public-private partnership to carry out a servicing project. Finally, Mr. Phil Meek, an independent consultant on space law and former Air Force lawyer on space issues, brought up the issue of salvage rights in space and the application of international humanitarian law (IHL)/law of armed conflict (LOAC) to OOS as it relates to its dual-use potential. He also stressed the importance of wording in any legal regime that governs space.

The next session was on "Information Sharing, Operational Considerations and Safety." Dr. Bryan Benedict of Intelsat General gave a GEO operator's perspective on OOS. He said that the return on investment is crucial, so they would have to compare and contrast life extension, rescue and inspection missions to see which would be best. He also noted that it is hard to make contingency plan for futures that have not happened yet, as the liability, legal, and policy challenges all are great. He ended by saying that the over-arching goal of commercial satellite companies is uninterrupted client services, so that will shape their viewpoint on everything, including OOS. Mr. Tim Rush of Aon ISB said that the space insurance market is ready to support OOS, but certain elements of early missions present challenges, which may best be addressed by governmental support and/or public/private partnership. He also commented on the commercial world being remarkable in its ability to cooperate if it is in everyone's best interests. Ms. Sarah Factor of the U.S. Office of the Secretary of Defense for Space Policy said that the U.S. Department of Defense's space situational awareness (SSA) capabilities were not built for the fidelity required of OOS. But DoD does support OOS missions of owner/operator partners that advance the security, stability, and sustainability of the space domain, as the larger responsibility we have is to the overall space domain. She ended by saying it is important to start to develop a dialogue about necessary requirements.

During the final session on "International Security and Stability," Dr. Eva Bernhardsdotter of the Swedish Defense Research Agency talked about the proposed draft international Code of Conduct (CoC) for outer space activities. Dr. Joan Johnson-Freese of the U.S. Naval War College said that the ambiguity of OOS technology leads to speculation which leads to a security dilemma, and asked the hypothetical question of what China could do to make the United States feel less suspicious if they were the ones doing OOS. Dr. James Fergusson of the University of Manitoba said that every OOS mission will have national security implications and wondered if OOS could end up making space safe for war by removing some of the negative consequences from the destruction of satellites.

Washington Workshop

The second event organized by DARPA was an invite-only workshop held on June 27, 2012, where a much smaller group discussed many of the issues raised during the previous day's panel sessions. It was held under the Chatham House Rule, which means that there is no attribution to specific speakers.

The first discussion of the workshop was on legal and policy issues of OOS. A few themes which had emerged during the previous day's discussions were that OOS' capabilities as a potential weapon was an impediment to international participation, and that the legal architecture of collaboration on OOS was unclear. The question was raised, how do we de-link satellites with weapons? The U.S. government was

warned not to let problems with OOS stopping it from moving forward with progress, but that it does need to talk about the elephant in the room: dual-use aspects of OOS. It was noted that there were three things needed to build trust for OOS: announce *a priori* the intent of the mission; have the operators report where the satellite is; and maintain a healthy distance away from other satellites during the mission.

It was argued that the economics do not warrant OOS at this time. It was posited that ADR is not the same as OOS, although the two have been used interchangeably to demonstrate the policy/legal challenges. ADR requires going up to bring something down, and often the servicer does not know much about the debris object (they may have some remote sensing data, but often the object has been abandoned for years). In contrast, OOS requires lots of planning and coordination, has to be done without destroying the serviced satellite, and necessitates knowing a lot about the satellite being serviced. One participant asked how much of ADR and OOS is industry and/or government looking for business, versus identifying an actual need? It was also pointed out that there is no economic model for OOS in LEO and so perhaps it should be a public responsibility, in that because public funding created this problem, public funding should be used to fix it.

The next session was on operations and safety, where specific examples of steps taken during actual OOS operations to improve safety were given. It was mentioned that the existing NASA documentation on rendezvous and docking with the International Space Station - the Interface Definition Document for International Space Station Visiting Vehicles - might be a good place to start for best practices, as it is the result of decades of experience and discussions with the ISS partners. Other suggestions included using navigation aids such as beacons, reflectors and transponders, as well as the need to test and develop OOS procedures outside of the active GEO belt in order to minimize the effect of possible accidents on active satellites.

One participant pointed out that the legacy SSA capabilities are in general not going to be able to verify OOS activities in either LEO or GEO. Once two objects close to within several kilometers in LEO or about 50 kilometers in GEO, it is extremely difficult to tell them apart via ground-based tracking. Even satellite operators in GEO are unable to distinguish between two satellites using transponders once they are within a couple kilometers of each other. This creates a significant TCBM challenge.

The final session dealt with international security and stability issues. One of the speakers pointed out that while China was a major focus during the first day's discussions, one country had not been discussed at all – Russia. The Obama administration started a reset in its relations with Russia, but that itself is being reset. Should the Russians be involved in OOS? Can they be?

In terms of settling concerns about international security effects of OOS, one engineer said that there were some technical steps which could be taken that could give others an idea of whether an OOS mission is what its operators say it will be. These include knowing what location the OOS is going to and what its business plan is; seeing what orbit going to, and determine where it can go from there; having lab visits to get an idea of maneuvering capabilities; finding out the technical and sensor capabilities; knowing their plan so that fuel usage during an operation could be determined; and confirming end of life.

It was pointed out that Switzerland's CleanSpaceOne ADR effort has been perceived very differently from other proposed projects. From the beginning, they were very transparent about what they had planned. It is a collaborative project run by an academic institution and is open to additional international cooperation and participation, plus the Swiss already have a reputation for being neutral. Their target is something that they themselves launched, so there are no liability concerns.

Given the emphasis that many speakers the day before had put on an international approach to OOS and ADR, one speaker brought up some issues to keep in mind when attempting international cooperative efforts. One was the purpose and value of greater regulation or governance. Regulations should not be instituted simply for the sake of regulating. Instead, a relevant problem should be

identified first and then regulation should be crafted to solve that specific problem. Regardless of whether or not the products from international initiatives perfectly solve the problems of space sustainability, it is crucial that these discussions continue to take place, and all relevant stakeholders must be informed about and empowered to play their appropriate role in these discussions.

Other questions to consider: what are the technological obligations for OOS and what kinds of joint efforts are even possible? Also, looking at other countries' ability to contribute to something like OOS, what are the capabilities available? Are they strictly civilian and governmental in nature, or are there reasonable, feasible private sector options? Alternatively, will working with the private sector unnerve other countries more used to government-backed space programs? Also relevant to this discussion is that often the United States has a different definition of what cooperation is than other countries do: the United States often views cooperation as data/systems/technologies being given by the United States to another country, while other nations want cooperation to be a two-way street where they have something of value to be included. As well, space programs of other countries tend to be scientific in nature, but anything international is often done via their Ministries of External Affairs, which can lead to bureaucratic confusion. Another institutional problem is that few countries have an organization in charge of strategic space assets, so would working with the U.S. military cause concerns? Finally, there is the question of leadership/prioritization – do other countries see OOS, ADR, and other RPO activities as key to the future of their space programs? If not, this may affect their interest in cooperative programs on these issues.

Washington Scenarios Workshop

On November 5, 2012, SWF hosted a small, closed workshop in Washington, DC, where it convened a meeting of roughly 25 U.S. government agency, private sector, and civil society experts to examine the non-technical regulatory challenges of RPO in greater detail. Specifically, the workshop focused on a handful of theoretical ADR and OOS scenarios designed to highlight key policy, operational, or legal issues and worked through them in a group discussion. The scenarios, though fictional, were based on actual concepts in development or being evaluated around the world or were composites of more than one existing concept. SWF was particularly interested in examining the following topics in this U.S.-based discussion: spectrum allocation management and coordination; technology transfer and licensing; compliance with international and national laws; communication and coordination with other space actors; and transparency and confidence-measures that might mitigate any negative misperceptions of an RPO activity.

The first scenario featured a private American company who had developed an operational debris removal spacecraft. It consisted of a 5-km long tether that used electrodynamic fields interacting with the Earth's magnetic field to maneuver without using fuel, as long as it had electrical power. This allowed the spacecraft to slowly maneuver in all orbital dimensions, including inclination changes. In this scenario, the Inter-Agency Debris Coordination Committee (IADC) was tasked to identify large, high-threat debris objects in LEO that should be removed. This private company then received funding and approval from the launching States of each of these five objects to remove them over a one-year period. After being launched into a 700 km x 700 km parking orbit, the spacecraft would proceed to rendezvous with the first debris object on the list and capture it using a net system. It would then maneuver over a period of several days down to an orbit below that of the International Space Station and release the debris object. The debris object would re-enter the atmosphere via natural decay in a matter of months. Meanwhile, the spacecraft would maneuver back up to grab the next item on the list and repeat the process.

The main issues raised in the first scenario discussion included ownership and liability, SSA and remote sensing in space, and the potential responsibility to contract the ADR service once it is available. First, there was a question of who would be listed as the launching State of the ADR spacecraft, especially if its services were being procured by foreign entities. Furthermore, in that case, workshop participants

questioned how the scheme would be impacted by restrictive U.S. export control laws, namely the International Traffic in Arms Regulations (ITAR). This issue would have to be determined before anything can be launched as it will affect the registering of the spacecraft in compliance with international law.

Second, several SSA challenges were brought up in relationship to this scenario. Without very precise and accurate, near real-time SSA, the spacecraft could not complete its mission in a safe and responsible fashion. Currently, the largest provider of SSA is the U.S. military's Joint Space Operations Center (JSpOC). With their current capabilities, they would not be able to manage the SSA and collision avoidance for the company's spacecraft – a 5-km tether constantly moving in LEO. This means that the spacecraft itself would have to have onboard, highly capable sensors, which brings up questions of remote sensing in space. There is currently no regulation for imaging in space, but such a capability moving through LEO is likely to raise a lot of national security and intellectual property concerns with space actors around the world.

Third, workshop participants wondered about the responsibility of space actors to use this service if it was fully operational and available. For example, if the owner of a very large and potentially dangerous piece of space debris knows that their spacecraft poses a serious risk to other operators in orbit and chooses not to use this service to remove it, does it change things in terms of liability and compliance with international law?

The second scenario involved a fictional, non-U.S. company that offered a satellite collision detection and avoidance service for satellite operators. The warning service used a geographically-distributed network of 100 optical tracking telescopes to detect small space debris, predict possible collisions with active satellites, and warn satellite operators. The avoidance service used a 5 kW ground-based laser to fire multiple pulses to change the orbit of a piece of debris that posed a threat to a customer's satellite, thereby alleviating the satellite from having to expend fuel to maneuver itself out of harm's way. The company also offered this service to the owners of large, dead satellites that had been left in orbit, preventing smaller pieces of debris from colliding with the expired spacecraft and thus causing more debris at the liability of the owner. The company planned to add the capability to remove small pieces of debris from orbit using its ground-based laser in the near future.

The very first question raised during the second scenario discussion dealt with security and strategic stability. Participants wanted to know how anyone could be sure that such a company or activity would not be mistaken for a rogue lasing event, especially considering the many anti-satellite (ASAT) capabilities of such a laser. There are also many safety issues associated with a ground-based laser like the one proposed in the scenario. If it were to work, it would have to be fully incorporated into air traffic control so as not to interfere with safety in flight. Ideally, there would be some sort of international clearinghouse that would to arrange blackout times so that the laser did not inadvertently blind sensors and so other actors would not misconstrue the lasing event as hostile or malicious. In addition to these concerns, SSA is a challenge in this scenario. Many SSA programs rely on modeling to determine the location of objects in orbit and a company such as this would be purposefully maneuvering objects and thus throwing off these models. Furthermore, what would happen if the company accidentally maneuvered a piece of debris into the path of another spacecraft? This would raise more questions and concerns about liability and who is responsible for accidents that might occur as a result of these activities. It was pointed out that current insurance policies exclude lasers, so this would be a major hurdle to overcome before such a scheme could be realized.

In the third scenario, an American company operated a service that could extend the life of satellites in the GEO region. The company has three small backpack satellites orbiting just below the active GEO belt. When contracted by a satellite operator, one of these backpack satellites would drift along the belt to the host satellite's location and maneuver to rendezvous. It would attach itself to the host satellite and takeover maneuvering and station-keeping duties for the length of the contract up to five years. The backpack

satellites would also be available to help a satellite reach its desired active orbit after being stranded in another orbit as the result of a launch system malfunction.

The discussion for scenario three focused largely on licensing and regulation of the backpack satellite and the relationship between it and the contracting satellite. One of the first topics to be brought up was the definition of a space object. This is currently unclear in international law and would likely pose a problem for the GEO backpack satellite company. Once the backpack attached to another spacecraft, do they become one space object or do they remain two separately registered and licensed objects? Who retains jurisdiction and control of the object according to Article VIII of the Outer Space Treaty? As international law is currently written, this would be very important should liability ever become an issue. Similarly, how would this service change life expectancy for the contracting spacecraft? End-of-life can play a critical role in licensing and international registration of spacecraft and would have to be considered when entering into any agreement.

The fourth, and last, scenario involved a U.S.-based commercial company that manufactured new communications satellites out of recycled parts from defunct satellites. Using technology originally developed by DARPA, the company operated a robotic vehicle in and near the active GEO belt to gather parts from hosted payload slots on active GEO satellites and use them to converts pieces of dead satellites in the GEO graveyard into fully-functioning satellites. The company worked to match customer requirements for the new communications satellites with apertures available on satellites in the graveyard, including the ability to negotiate transfer of ownership of the aperture from the original owner. After an aperture got converted to a fully functioning satellite, the company would conduct a checkout of all major systems before handing it over to the customer. In many cases, customers would use these newly created satellites as part of a cluster operating in a GEO slot.

The fourth scenario discussion focused on three main areas: ownership and registration of the newly-created spacecraft vs. the original, spectrum licensing and radiofrequency interference, and how to conduct such an activity transparently. Similar to the other scenarios, the issue of ownership and registration was key to this discussion. This case raised questions about the original spacecraft from which a recycled part was retrieved and the new spacecraft created with the recycled piece. Would entirely new licenses and registrations be required for all involved spacecraft after the service was completed? If an antenna, for example, was attached to a satellite in GEO, would this require a separate ITU registration and allocation? It is unlikely that the altered spacecraft would fit the current registration. This then involves a whole host of other considerations including the ITU registration process, concerns about equitable allocation of slots and frequencies, and the length of time it takes to go through the ITU registration process.

Even if this issue was effectively addressed, spectrum issues would also pose a problem. In the United States, the current authority for regulating commercial spectrum use is the Federal Communications Commission (FCC), which is currently unable to deal with such a request. Some ideas were proposed to address this shortcoming, such as the robotic vehicle using the global footprint vacated by the Space Shuttle program, but again, it is not clear what process the company would follow to get the spectrum needed to conduct its activities safely. Finally, concerns about unintentional interference would need to be addressed. This is in terms of interference both caused by the spacecraft and by other spacecraft that might interfere with its safe operations, since it will have to maintain communication while operating.

Finally, any type of activity like this would have to be extremely transparent so as to alleviate what will likely be many concerns around the world over the ASAT capabilities of such a system. In its Phoenix program, DARPA plans to make announcements of each stage of its activities, but who would these announcements be made to in the fictional scenario? Would this be sufficient to allay concerns? There was much discussion about mounting a video camera on the spacecraft and live streaming its actions, but spectrum issues would be major with that plan, as

well as concerns over trade secrets being revealed through the video feed.

B. Brussels, Belgium

On October 30, 2012, in partnership with the Institut francais des relations internationales (Ifri), SWF held a public conference on OOS and ADR in Brussels, Belgium, in order to engage the European community. Specific topics that were addressed included the dual-use nature of OOS and ADR technologies, norms of behavior for conducing OOS and ADR activities, and TCBMs to reduce the risk of such activities being seen as threats. The conference was held under the Chatham House Rule.

SWF's Dr. Michael Simpson and Mr. Christophe Venet of Ifri opened the conference providing a context to the discussion and a quick briefing on the first conference in Washington DC. This was followed with a panel which gave an overview of current and planned OOS and ADR activities in Europe. Speakers were selected from those countries/institutions in Europe that have been most active in the discussed topic: European Space Agency (ESA), German Aerospace Center (DLR), and the Swiss Space Center.

ESA presented its Clean Space initiative, which is seen by the agency as a pro-active answer to the environmental challenges both on Earth and in space (including ADR), including its own operations as well as operations performed by European space industry. DLR presented its approach to OOS by demonstrating the availability of technology and verification procedures and techniques for rendezvous, capture, maintenance and removal of an uncontrollable satellite from its operational orbit through a demonstration mission, DEOS (Deutsche Orbitale Servicing Mission). Finally, the Swiss Space Center talked about the development of critical and innovative technologies needed for ADR through its Clean Space One project.

Mr. David Barnhart from DARPA gave a detailed summary of DARPA's June 2012 Conference on "Fostering Sustainable Satellite Servicing" in Washington, DC. This summary was followed by a general overview of international security and stability challenges with OOS and ADR, given by Ms. Tiffany Chow of SWF.

Legal challenges with OOS and ADR were the hot topics of the conference. An overview covered major components, including sovereignty, liability, and the definition of space debris. There was a heated discussion involved with this panel because there was a lot of criticism toward the ESA's Envisat, a very large remote sensing satellite in low Earth orbit. Envisat was launched in 2002 with 10 instruments aboard and at eight tons is the largest civilian Earth observation mission [10]. Envisat's mission lasted ten years, more than twice its designed lifespan. The Envisat mission ended on April 8, 2012, ESA lost contact with the satellite [11]. Envisat's large size and location in one of the most crowded regions of LEO makes it a considerable long-term space debris risk [12].

The perspectives of the commercial sector on ADR and OOS were very interesting. They included presentations from insurers, satellite operators, satellite manufacturers, and investors (SES, Thales Alenia Space, EADS Astrium, JKIC, and Argo Assurance). It appeared that OOS was of a high interest to the private sector – more than debris issues. As much as the industry is aware of debris threats, currently it is a lot more concerned with space weather's impact on their satellites and jamming, as it perceives those as being a lot more frequent and "real" threats than debris currently is.

The last panel focused on international cooperative initiatives on space and their relationship with ADR and OOS. An overview was given on three initiatives in particular: the proposed International Code of Conduct, the COPUOS Long Term Sustainability of the Outer Space Working Group, and the work of the Group of Governmental experts on Space focusing on Transparency and Confidence Building Measures. Clear statements were made that these three parallel initiatives should not be competing but should rather complement each other's work. It was argued that due to the fact that the international community has been actively working on sustainability issues some sort of a progress should be made in the upcoming years, which, therefore, should positively impact the issues of ADR and OOS.

C. Singapore

SWF organized two events in Singapore in February 2013. These events were held in partnership with the Singapore Space and Technology Association (SSTA).

Singapore OOS and ADR Scenario Workshop

The first event in Singapore consisted of a half-day, closed-door discussion of potential OOS and ADR scenarios held on Feb. 19, 2013. Attendees included experts in the fields of space policy, space law, and space operations from the United States, Australia, Japan, China, India, Switzerland, Germany, and Canada.

As in the November 2012 workshop in Washington, DC, the discussion centered on scenarios of possible ADR or OOS activities in space and the legal, policy and international political challenges they might engender. The two scenarios were the use of lasers for a ground-based collision warning and avoidance service and the commercial company that recycled parts of dead satellites in orbit to create new satellites.

A significant element of the discussion focused on the use of lasers. Significant questions were raised about the ability of such a service to offer realistic warning times before collisions and the ability of a customer to make informed decisions based on the inherent uncertainties involved in the process.

Several participants focused on the need for international coordination of such a service. Laser firings would need to be deconflicted with both aircraft in the area and the overflight of satellites with active optical payloads. Although the risk of any actual damage to aircraft or satellites would be very low, the potential threat in the minds of the aviation world and satellite operators would pose a significant obstacle to such a service being allowed to operate.

Thus, there would need to be significant steps taken by the operators of any service that used ground-based lasers to fire into space to increase transparency and confidence in their operations. Some participants also weighed the value of international regulations of the use of ground-based lasers being fired into space. However, since such lasers are already widely used today without such regulations, it was generally felt that, barring a significant incident of irresponsible behavior, such regulation could be left to the national level.

Significant legal questions arose around the liability of such a service. If the company was paid to move a piece of debris to avoid the collision, and the same piece of debris later struck another satellite, would the company be liable? This is a particularly tricky question to answer, as in the time interval between the changing of its orbit and the collision the piece of debris would have had its orbit modified further by a number of natural forces.

Legal questions also arose regarding issues of the sovereignty of space objects. Launching States retain jurisdiction and control over space objects in perpetuity. Altering an object's orbit could be seen as a violation of the launching State's sovereign control. However, this only applies to space objects on a State's national registry. The vast majority of objects (i.e., virtually all those aside from objects that were at one time functional satellites) have never been registered by any State. Furthermore, it would be virtually impossible to determine the launching State for the hundreds of thousands of pieces of space debris between one and ten centimeters, a necessary step if prior permission to alter the objects orbit is required.

Participants also discussed the ethics of such a service. A collision avoidance service could be seen by some as a type of protection racket, where satellite operators have no other choice but to pay for the service to protect their asset, particularly satellites without maneuvering capability. This might instead lead to establishing a different model of offering such a capability as a public service such as police or fire fighting.

During discussions of the second scenario, the concept of launching State took center stage. The existing international legal framework does not offer a way for a launching State to absolve itself of responsibility for a space object. Therefore, using pieces of a defunct space object to create a new object would likely mean the launching State(s) of the defunct object would transfer to the new object.

If so, this could be an unwanted assumption of responsibility on behalf of these States and a significant legal complication to operation of the new satellite. Resolving it would require significant negotiation between the States involved culminating in agreement on responsibilities and contracts to enforce those responsibilities.

A second major thread in the conversation involved the dual use aspects of such operations. If an actor possessed the ability to dock with and alter a space object, other actors would likely be extremely concerned about such activities endangering their own satellites. One discussant posed the notion of commonly-agreed upon "exclusion zones" around satellites as a way of helping inform clarity of intent.

This lead to a discussion of the need for "rules of the road" for activities in space as a way of establishing norms of behavior. The analogy was made to driving on two-lane roads. This is an inherently risky activity unless there are established norm for which side of the road is driven on and belief that those norms will be followed.

The discussion then turned to the need to involve the full spectrum of spacefaring countries in discussions on space activities. Most participants agreed that ADR and OOS are a "first-world" problem to some degree because they are the only countries with the resources to undertake such activities at the moment. However, all countries interested in space, regardless of their degree of capability, need to be aware of these activities and involved to some degree in discussions on creating norms of behavior. These discussions will also need to take into account the various regional dynamics, and in some cases lack of interdisciplinary interactions and communication within emerging/develop space actors.

Perhaps the most significant takeaway from the workshop discussion was the need to do an example ADR or OOS mission and not wait for all the legal and policy issues to be settled beforehand. While there are ambiguities and grey areas, the consensus among the workshop participants was that there was not anything in the existing law outright preventing ADR or OOS, and having one or more actual missions taking place would play a strong role in helping establish the norms of behavior in doing so and clarifying the grey areas. If something happened during an experimental mission that was deemed a problem, the lawyers could then deal with it afterwards, as opposed to trying to find and solve all the problems before allowing any activities to take place.

Singapore Conference on On-Orbit Satellite Servicing and Active Debris Removal

The second event held in Singapore was a full-day public conference. The conference was a continuation of the discussions previously held at the conferences in the United States and Belgium and in general followed the same format.

The first session featured specific OOS or ADR projects in various countries. Ms. Satomi Kawamoto presented an overview of space debris mitigation and removal studies being conducted by JAXA. Mr. Dan King from McDonald Dettweilier and Associates in Canada summarized his company's developments in robotic capabilities to support ADR and OOS. Professor Volker Gass from the Swiss Space Center outlined their plans to deorbit a small cubesat as part of the CleanSpace One project. Mr. Joe Anderson from ATK in the United States discussed their Vivisat satellite life extension project. Finally, Dr. Craig Smith from EOS Space Systems in Australia discussed his company's ground-based laser capabilities for detecting and tracking space debris.

The conference then turned to two summary presentations. Mr. David Barnhart from DARPA presented a summary of the conference and workshop they held in Washington, DC in 2012, as well as the Phoenix project itself. Mr. Brian Weeden from SWF presented an overview of SSA and why improving SSA for all space actors was essential for ADR and OOS activities. In particular, Mr. Weeden highlighted some potential requirements for safe and transparent ADR and OOS that current SSA capabilities are not able to provide.

The afternoon session of the conference began with a discussion of the legal challenges inherent in ADR and OOS. Dr. Yaw Nyampong from McGill University provided a summary of the legal issues drawn from the existing international space treaties. Specific issues revolve around the need for a mechanism by which a State conducting debris removal can seek consent from the State of registry, or perhaps a mechanism by which a State of registry to declare its space objects open for removal. Dr. Nyampong's remarks were followed by a prepared speech by Wing Commander Duncan Blake from the Royal Australian Air Force. He focused more on the

security issues involved in ADR and OOS, and presented some thoughts on establishing exclusion zones around spacecraft as part of developing norms of behavior for ADR and OOS.

The next session at the conference was a panel discussion on commercial perspectives on ADR and OOS. It was moderated by Mr. Joerg Kreisel, a long-time space entrepreneur, who began by presenting an overview of the history of ADR and OOS efforts by both the public and private sector over the last decade. The discussion focused largely on the motivations of private sector over this time period, and the evolution of the business case. The participants noted the importance of public-private partnerships in both developing the relevant technologies as well as the market.

The conference concluded with a panel discussion on international perspectives on the security dimensions of ADR and OOS with participants from the United States, Japan, India, China, and Australia. There was general agreement on the importance of space sustainability as a policy issue, although it was noted that emerging and developing space actors are likely to place less significance on it. There was also agreement on the inevitability of some sort of "Asian space race" between India, China, and Japan, and establishing norms of behavior is critical to tamping down some of the potential negative consequences of such a race.

The Australian participant highlighted some of the public policy challenges that all nations face on these leading edge space issues. These include putting in place relevant national legislation and mechanisms to deal with them, developing strong inter-departmental expertise and coordination, and focusing more on the priorities and end goals rather than just the technology. Finally, there was universal agreement that all spacefaring countries needed to be involved in discussions of norms of behavior and rules of the road, regardless of their level of capability. Although it may make the discussions more complex in the short-term, it will have important benefits in the long-term for building trust, understanding in and adherence to the norms, and help raise awareness of critical sustainability issues among emerging and developing space States.

III. Main Themes and Next Steps

Taken together, there were several recurring themes throughout the discussions during these six events. The first theme is that while the current international legal framework does not explicitly forbid ADR and OOS, the existing international and national mechanisms for implementing that framework do not address many of the challenges raised by ADR and OOS. This places RPO activities firmly in a legal "grey area" with significant uncertainty that is not conducive to widespread commercial activity. With the private sector pushing many of these activities forward, it is up to governments working with industry to address the policy and regulatory shortcomings to enable these new opportunities.

A second recurring theme is that "blue sky" discussions of the legal and policy challenges in RPO are only useful to a point. Broad, open-ended discussions can be useful to frame issues and identify gaps in the existing legal and policy frameworks, but they are not very useful in figuring out how to address those gaps. More targeted discussions focused on specific examples of RPO activities can be more effective in this regard, particularly when they include the relevant stakeholders in government and industry. More than once during these RPO events, a briefing from a private company on their specific plans prompted government agencies to identify a gap in their regulatory mechanisms and bilateral discussion between the two on how to address the shortcoming.

A third recurring theme is the importance of TCBMs for ensuring RPO can be done in a safe and secure manner. Two important elements of TCBMs for safe and secure RPO are improving SSA for all space actors and coordination between space actors. Currently, some SSA and coordination is done on a limited scale by the U.S. military's JSpOC. However, the JSpOC's purview, focus, and customer base is largely limited to U.S. military activities in space. A few other countries also operate even more limited space operations centers, but in general there is a lack of coordination and information sharing among all countries and the private sector. This information

sharing and coordination needs to improve dramatically for RPO to be successful.

A fourth theme closely related to TCBMs is developing norms of behavior, and here too progress is needed for ensuring the safety and sustainability of RPO. The norms of behavior developed for RPO need to address two basic issues: improving safety and minimizing the opportunities for misperceptions and mistrust. The norms of behavior for safety need to incorporate the body of knowledge on how to conduct RPO in a safe manner and would likely be of an engineering and technical nature. On the security side, the norms need to focus on the use of dual-use technologies in orbit and would likely be of a political and operational nature.

A fifth theme that emerged from the discussions is the need to involve all the relevant stakeholders in developing national regulatory mechanisms, TCBMs, and norms. At the national level, there needs to be dialogue between various government agencies with competence for space activities and between the government, the private sector, and civil society. This process needs to happen as early as possible in the planning stage for RPO. At the international level, there needs to be an opportunity for emerging and developing space States to participate, should they so choose. This would significantly increase the legitimacy of any resulting norms and also help ensure those States in the process of developing their national policy and regulatory mechanisms.

Finally, many participants in these various events highlighted the importance of one or more RPO demonstration missions for tackling the legal and policy challenges. Ideally, such demonstration missions would involve more than one country and both government and private sector actors. The demonstration missions would provide concrete examples of RPO with their associated specific legal and policy challenges. The missions would force the relevant actors to solve those challenges, and in doing so lay the groundwork for establishing the mechanisms, TCBMs, and norms necessary for future RPO to occur in a safe, secure, and sustainable manner.

All of the participants in these discussions noted that much more dialogue and work was needed to addresses the challenges of RPO in general as well as ADR and OOS. There was consensus that these activities will be a key part of future human activities in space. Addressing the legal and policy challenges that these activities pose is critical to not only enabling them but also ensuring that they contribute to the safety, security, and long-term sustainability of the space domain instead of detract from it.

The dialogue on addressing the non-technical challenges of RPO, ADR, and OOS needs to continue on multiple levels. At the international level, there needs to be continued discussion between all interested States on developing norms of behavior and best practices for RPO, ADR, and OOS. At the national level, government institutions need to put in place the appropriate policy and regulatory mechanisms to ensure these activities are carried out in accordance with international law. These discussions should take place in coordination with the governmental and private sector actors who are planning such activities. In addition, the dialogue needs to occur across legal, policy, and technical disciplines as well as within each individually.

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