Space Policy 47 (2019) 217–223

Contents lists available at ScienceDirect

Space Policy

journal homepage: www.elsevier.com/locate/spacepol

To Clear or to Eliminate? Active Debris Removal Systems as Antisatellite Weapons

Bohumil Dobos (Bohumil Doboš)*, Jakub Prazak (Jakub Pražák)

Institute of Political Studies, Faculty of Social Sciences, Charles University, U Kříže 8, 158 00, Praha 5, Jinonice, Czech Republic

ARTICLE INFO

Article history:
Received 22 September 2018
Received in revised form
27 December 2018
Accepted 18 January 2019
Available online 15 February 2019

Keywords:
ASAT
Active debris removal
Dual-use
NewSpace
Space debris
Space security
Space traffic
Space weapon

ABSTRACT

Outer space is a congested strategic domain. The issue of space debris mitigation is one of the key issues of safe space traffic. However, active debris removal (ADR) systems may raise concerns about their dual-use capabilities. In this article, the authors have analyzed the ADR systems focusing on their potential as space weapons. The article concludes that ADR systems can be utilized for harmful purposes, although with limited impact. This limited potential of ADR systems to become antisatellite weapons allow for the development of such systems keeping in place basic confidence and trust building measures. The authors believe the further commercialization of space sector could enhance the space debris mitigation efforts.

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1. Introduction

Outer space can be—together with land, sea, air, and cyberspace—defined as an independent strategic domain [1]. Despite the limited level of utilization of outer space itself as a consequence of the insufficient level of maturity of the technology, we can already identify many spheres of human activity dependent on the utilization of space assets. This is consequently connected to the rising amount of orbital traffic. The density of the satellite network is then especially high in low Earth orbit (LEO) in the altitude of 200–2000 km [2]. The region is getting increasingly congested, and the number of operational satellites is moreover set to increase [3]. This further increases the need to solve the pressing issue of the sustainability of the spaceflight given not only the number of operations taking place in orbit but also the problem of orbital debris. The Inter-Agency Space Debris Coordination Committee (IADC) defines orbital debris as "*(…) all man-made objects including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional.*" [4] The problem with the growing number of space junk is highly topical and directly threatens the sustainability of space travel.

There are two broad sets of actions that can be taken to tackle the problem—passive and active mitigation. Passive guidelines are presented, for example, by the IADC to name just one example and include a code of conduct or other guidelines regarding the activities of the satellites nearing the end of their lifetime and nature of operations throughout their active life-span. These may include prevention of explosion or establishment of protected zones that are to be left vacated by the dysfunctional assets [4]. On the other hand, there are active measures, which are regarded as necessary for the future of operations on Earth's orbits. These measures seek an active deorbiting of pieces of debris to decrease the possibilities of collisions [5]. A crucial part of the architecture is the development of an active debris removal (ADR) system that would enable manipulation with the non-functional objects. There is, nevertheless, a significant potential problem with the utilization of such a system. This issue stems from its theoretical usefulness in targeting operational satellites thus turning it into an antisatellite (ASAT) weapon.

The following text evaluates the possibility of such misconduct that would endanger the potential clearing operations. It tries to solve the question of whether the ADR systems can be effectively utilized as ASAT weapons. Furthermore, it draws some

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* Corresponding author.
E-mail addresses: bohumil.dobos@gmail.com (B. Dobos), prazak.jakub94@gmail.com (J. Prazak).

https://doi.org/10.1016/j.spacepol.2019.01.007
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recommendations as for how to ensure that the clearing operations can take place in a context of the findings. The article is structured as follows. The first section is dedicated to the brief framing of the contemporary international setting in outer space that guides the underlying logic behind the considerations regarding the ADR systems. We then follow with the introduction of two key topics that guide the ensuing debate—ASAT systems and orbital debris. Following, the debris mitigation methods are presented. The final part analyzes the utility of the ADR technology as ASAT weapons.

2. Astropolitics in the 21st century

International space politics in the 21st century are defined by two main developments—a shift toward more conflicting relations among some of the major space powers and an increase of the number of space actors with a special place of the so-called NewSpace actors inside this growth. In the following section, we will look at both of these processes to frame the consequent research.

There is a sense of growing tensions following the relatively calm period of space development of the 1990s. This situation follows the development of terrestrial international relations [6] and is mainly connected to Sino-American competition [7]. Following the dissolution of the Soviet Union, the United States became the hegemon of space politics. The U.S. military is also comparatively the most dependent on the utilization of space assets and, especially following the rise of nationalism inside the U.S. foreign and space policy following the events of 9/11, it turned toward a higher level of a security-oriented framework. This process is manifested by the recent claims of U.S. president Donald Trump regarding the establishment of a space force as an equal branch of the U.S. armed forces.

The primary target of the insecurities nowadays is China. The external perception of the Chinese space program is somewhat controversial. For example, Tellis [8] emphasizes the Chinese militarization of its space program, while Zhang [9] points out to the peaceful consequences of Chinese space operations. Without a doubt, China runs many advanced and high-tech programs involving the development and utilization of a wide array of space assets. According to Zhang [9], however, major space programs such as Program 863 or Program 921 do not have military motivation. On the other hand, a vast majority of the space systems have dual-use capabilities so the civilian nature of the technology, given the high level of secrecy clouding the projects, can be disputed. Moreover, China is working on many counter-space systems utilizing electric, energetic, or direct attack weapons, and the Chinese space advancement can be perceived as a part of the Chinese grand strategy [10]. In this discussion, we can observe the problem with the identification of intent as the primary factor dividing military and civilian technologies. Given the dual-use nature of 95% of space assets [11], the same satellite can usually be used for both civilian and military purposes. In the case of China, the intent is unknown [7], and its space program is controlled by the military [12], which adds to the United States and global uncertainties. Nevertheless, it is important to point that other space actors also struggle with a lack of clarity regarding their space programs' intents but in a comparatively lower degree.

The United States is aiming to retain its space superiority. The U.S. Air Force Doctrine Document defines space superiority as "*the degree of dominance in space of one force over another that permits the conduct of operations by the former and its related land, sea, air, space, and special operations forces at a given time and place without prohibitive interference by the opposing force*." [13,14] The document states that the U.S. Air Force's counter-space operations are "*the ways and means by which the Air Force achieves and maintains space superiority*" [14], and the United States desires to ensure that its space superiority remains unchallenged [13,14]. Furthermore, the document distinguishes between "*defensive counterspace operations preserve US/friendly ability to exploit space to its advantage via active and passive actions to protect friendly space-related capabilities from enemy attack or interference*" and "*offensive counterspace operations preclude an adversary from exploiting space to their advantage*." [14] The U.S. policy of dominance-seeking was further presented in the 2018 National Space Strategy, that following other policies of Trump administration seeks to place *"America First Among the Stars"* and set up *"peace through strength"* [15], thus to some degree revising the writings of E. Dolman [16]. The strategy aims to establish more resilient space architectures, strengthen deterrence and warfighting options, improve foundational capabilities, structures and processes, and foster conducive domestic and international environments [15].

In practical terms, the United States tried to show their space dominance in 2008 by de-orbiting the USA-193 using modified Standard Missile-3 (SM-3). It may be disputable whether this was a necessary action to prevent contamination from 454-kg hydrazine tank attached to the satellite in case it survived re-entry or a pure demonstration of power [17]. This action was, nevertheless, an apparent reaction to the 2007 Chinese ASAT test that not only restarted the process of the testing of weaponry that was halted in 1985 but also created the largest one-time event increase of orbital debris [18–20]. Besides, we cannot forget the competition taking place among Asian spacefaring nations [10], increasing tensions between the West and Russia and other sources of tensions. This environment thus in no small degree shapes our thinking about the ADR systems.

The second important topic is an emergence of the so-called NewSpace. This phenomenon can be briefly defined as an introduction of commercial, entrepreneurial actors in the space domain [3,21]. These actors present not only a wholly new profit-based logic to the process of space utilization but also introduce new activities and markets with the potential to significantly increase the number of assets placed in outer space. This is connected to two processes. The first is the attempt to make space activities cheaper. A logic of the NewSpace actors is commercial—they need to make a profit out of the newly emerging opportunities. As space activities get cheaper, it is highly likely that the number of space assets will get up. The second issue is the planned development of mega-constellations. These systems aim to utilize an enormous number of small cheap satellites to provide a specific function (e.g., provision of free Internet connection) on a global level. As these small satellites are not navigable and will increase the number of assets in LEO two or three-folds (if we follow plans of companies like SpaceX [22] or OneWeb [23]), they might pose a huge problem regarding the congestion of Earth's orbits [21]. The situation is also problematized by the insufficient legal framework regarding the operations of private entities.

3. Antisatellite weapons

ASAT weapons are systems aiming to actively disrupt satellites operations in outer space. They are divided into Earth-space and space-space versions based on where the weapon is stationed [24]. According to available information, there are currently no weapon systems stationed in outer space. All ASAT weapons tested in the recent years are either kinetic Earth-based or utilize cyberspace and jamming and other interruptions of signals. There are many types of systems that can be considered as an ASAT weapon. These include, for instance, lasers, technologies disrupting radio frequencies, or other jamming technologies. Nevertheless, for the purposes of this article, we include only direct-ascent kinetic ASAT weapons as the different types are not connected to the development of ADR technology. These weapons are very similar to antiballistic missiles consisting of kill vehicle and a booster [25].

Currently, operational ASAT technology makes use of kinetic energy of the impactor that itself alone is efficient enough to disrupt the satellites that do not contain a defense mechanism. Thus, the ASAT weapon does not require the inclusion of an additional explosive device. The only limitation is, therefore, their ability to reach the target. Several actors are capable of utilizing this technology. To begin with, the United States has conducted various ASAT tests since the beginning of the Cold War. They are also probably the most potent actor regarding the possible conduct of military strikes in the orbital space. In 2008, the United States carried out an ASAT test in an altitude of 240 km with a modified SM-3 missile launched from the antiballistic missile Aegis system. The possible efficient range of this system may differ according to missile specifics. The older type Block IA is capable of reaching an altitude of 600 km whereas more recent Block IIA is effective in altitudes between 1450 and 2350 km [26].

The Soviet Union throughout the Cold War conducted numerous ASAT tests. Nevertheless, the current Russian capabilities are difficult to estimate since the Russian tests lack any official statements or data specifications. Sources suggest that the Russian kinetic ASAT efforts rest upon PL-19 Nudol missile that could possibly reach medium earth orbit (MEO) [27–30]. The infamous Chinese ASAT test in 2007 involved the modified mid-range DF-21 missile. DF-21D antiaircraft missile has an operational range of approximately 1500 km [31]. The DF-21 utilized in the test was able to reach a height of between 1000 and 1200 km with the payload of 600 kg. Thus, China could efficiently endanger the LEO systems [32]. The Chinese have also conducted a direct ascent ASAT test near the geosynchronous orbit (GEO) at least on one occasion in 2013 [33]. Finally, India claims their ASAT missiles are capable of an efficient strike to 200 km, already reaching the orbital path of some of the satellites. Moreover, the Indian Agni III mid-range missile of the range between 3000 and 5000 km should be theoretically able to approach targets in LEO [34]. This claim, however, is hardly verifiable, and the Indian ASAT capacity seems to be very limited.

The states mentioned above possess capabilities that make them capable of conducting space warfare in LEO. This, therefore, endangers the majority of current satellites. However, it is not confirmed whether the existing ASAT weapons would be capable of effectively reaching the MEO or high earth orbit (HEO), where the navigational or early warning systems satellites are located. In this context, Tellis [8] argues that Intercontinental Ballistic Missile (ICBMs) can be relatively easily modified into ASAT weapons. This means that the reach of ASAT weapons could be estimated by the range of the most potent ICBMs (despite the complicated process of their repurposing connected to the removal of nuclear warhead and replacement of the guidance systems). For instance, the range is of the Russian SS-18 Satan is 16 000 km and American UGM-133 Trident 11 300 km [35]. Since the use of such missiles as ASAT weapons must consider the ballistic trajectory included in the calculation of the effective range of ICBMs, the maximum altitude of these would be the half of that distance at best [32]. Still, Tellis [8] claims that even Chinese DF-31 missile with its range of 11 200 km [35] could ascent to geostationary orbit. Moreover, according to Forden [36], the DF-21 could reach similar altitudes if constructed as a specific direct ascent ASAT weapon.

The possible use of ASAT weapons holds several implications. First, it would lead to the introduction of warfare into the space domain. This can lead to a consequent development of space weapons and introduction of violent clashes in the space domain. Second, ASAT strikes significantly increase the amount of orbital debris. This would, in turn, disqualify even the attacking state from using the domain similarly to its opponent. Utilization of kinetic ASAT weapons is a spoiler of all space activities. This means that any actor that wants to keep utilizing its space assets will have to refrain from the use of kinetic ASAT attacks on a larger scale. Third, an attack on the asset that is not owned by the actor conducting the attack is illegal and constitutes an act of war. This can have consequences on all levels of international relations. Fourth, the massive development of ASAT technology would make the whole environment much harder to utilize and more unpredictable. This would in effect decrease its relevance for all space-faring actors. Also, direct ascent kinetic ASAT technology is one of the examples of space systems that are purely military meaning they cannot pose as a dual-use system with potential civilian utility. This means that progress in its development cannot be masked behind any civilian purpose.

4. Orbital debris

In 2010, the U.S. Space Surveillance Network (SSN) tracked around 14,000 objects larger than 10 cm in diameter orbiting the Earth (currently the number is at around 23,000). The SSN is capable of recognizing objects between 5 and 10 cm in LEO and object bigger than 1 m on the geostationary orbit. Other sources note that there are more than 22,000 objects larger than 10 cm located on orbits around our planet. The majority of them are located in LEO. Even though these numbers take together both functional satellites and orbital debris, the majority of them comprises of the latter. It is estimated that the Earth is orbited by approximately 500,000 pieces of space debris larger than 1 cm. It is important to realize that these objects orbit with a high velocity and cause potential danger to all the operational systems. Moreover, objects larger than 10 cm can be torn apart into other smaller pieces thus further aggravating the problem. NASA predicts that the amount of space debris will be expanding. Therefore, the risk of collision will increase [2].

The discussion regarding the Chinese ASAT test in 2007 put even higher emphasis on an agreement that the intentional destruction of the space systems that would endanger outer space activities should be avoided. China used a kinetic ASAT missile to destroy one of its own satellites, Fengyun-1C. The test was conducted at the altitude of 850 km [37], and most of the debris remained on orbit. Following the destruction, over 2,300 tracked pieces of space debris and estimated 150,000 pieces bigger than 1 cm were created which corresponds with 25% of all tracked objects around the Earth [38]. Thus, China, that itself is a member of the IADC, undeniably violated the guidelines. Nevertheless, the code of conduct regarding the passive protection against the orbital debris issue is not legally enforceable or its transgressions punishable [2].

The second major source of the massive orbital debris increase consists of unintentional collisions. In 2009, Iridium 33 satellite crashed into the discarded Russian Cosmos 2251 satellite. The resulting increase in the number of orbital debris in the altitude of 570 km was 70%, and the cloud endangered the Hubble telescope. In the same year, the International Space Station was threatened by a piece of space debris and had to change its trajectory. This maneuver needs to be conducted regularly in response to other pieces of orbital debris. Moreover, even without new orbital launches and introduction of new assets to the Earth's vicinity, some collision will take place every 2 to 3 years [5,39]. Hence, the issue of the orbital debris removal must be taken into consideration.

On the side of passive mitigation, the IADC established basic guidelines regarding responsible behavior in outer space that are widely accepted across the global space community. Similarly, the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space set up a Long-Term

Sustainability Working Group introducing technical content and definitions of the IADC debris mitigation guidelines with the aim to establish more precise principles considering the UN principles and treaties on outer space [40]. Basically, the IADC described three disposal options. First, to navigate the non-functional satellite debris into an orbit with a lifetime lower than 25 years. Second, to place the piece of debris at least 235 km above the GEO. Lastly, to maneuver the system into a region between the LEO and GEO, with a minimum altitude of 2000 km above the Earth's surface and the maximum of 200 km below GEO [41]. However, there are no binding mechanisms requiring space organization to follow these guidelines. The states tend to follow their own amended principles and rules by referencing the UN treaties and principles [40].

The second critical part of the debris mitigation process is ADR. The first step regarding the debris removal consists of monitoring the used orbits and identifying the objects that are to be removed. The second is legal—only a launching state can legally manipulate its own objects even following the end of their active life-span, and thus all the pieces of debris can be removed only with the explicit consent of the state owning the assets [5]. As pointed out by Rajapaksa and Wijerathna, "*the control of all space objects and the jurisdiction of matters relating to space objects are held by the launching state, according to the convention.*" [40] Moreover, the debris catalog distributed by the U.S. military is not accurate. The Russian coverage is similarly incomplete. The European data as gathered by the European Space Agency (ESA)/European Conference on Optical Communication registered about 200 more pieces of debris than the U.S. database [40]. There is also an issue of a connection between small pieces of debris and launching state that makes a legal side of the clearing efforts even more problematic. The next step is to develop technology capable of removing the dysfunctional systems from the active orbits.

5. Active debris removal systems

The ADR systems aim to dislocate a dysfunctional system (piece of orbital debris) using another vehicle in the process. Therefore, the advantage of ADR is that it may be used for all kinds of objects disregarding previous consideration about their removal [41]. There are also projects regarding laser-based systems, but given the higher level of maturity of the kinetic systems, we will present these as more probable to become available in the near future. The first issue connected to the ADR systems is the capturing method. Generally speaking, there are two fundamental principles of capturing an object—stiff and flexible. Stiff connection includes techniques like tentacles, single arm, multiple arms, and mechanical effector. The flexible connection can be divided into net capturing, tether-gripper, and harpoon mechanism [5,42]. Let us now take a closer look at some of these methods.

Tentacles are easy to be tested on the ground and have higher technology readiness level. Disadvantages are complicated rendezvous phase, the need for accurate relative positioning and velocity and are possible to be bounced. The single arm is similarly easy to be tested on the ground and has higher technology readiness level. On the contrary, there is a high probability of collision, the method requires a grappling point, and the rendezvous and docking are complicated. Multiple arms are easy to test on the ground and have flexible capturing. Unfortunately, they have a sophisticated control system, higher mass, and cost and require rendezvous. Net capturing allows a large capturing distance, reduced requirement on precision, and is compatible with the different size of debris. On the other hand, net catching is hard to control, hard to test on the ground, and there is a risk of critical oscillations. The pros of tether gripper are large capturing distance, short capture operational time, and lower mass and cost. The cons are lower reliability, requisition of grappling point, and the difficulties of ground testing. A harpoon does not need a grappling point, allows a stand-off distance to the target, and is compatible with different target types such as rocket body or satellite. On the other hand, its drawbacks involve the risk of generating fragments or risk of a breakup of the captured satellite [5,42]. The pros and cons of the different methods are summed up in Table 1.

Following the capturing of the dysfunctional object, it is essential to remove it from orbit as well. Not all removal methods, nevertheless, require previous capturing of the asset. The possible techniques include drag augmentation system (consisting of foam, inflated, and fiber-based method), electrodynamic tether, solar radiation force, contactless removal methods (artificial atmosphere influence, laser system, and ion beam shepherd), and contact removal methods. Drag augmentation system can operate on a considerable distance and is compatible with the different size of debris. On the other hand, it possesses the risk of breakup and is less efficient compared with other methods. Electrodynamic tether does not need a propulsion system and has high technology readiness level but requires capture and is unavailable in GEO. Contactless removal is on the one hand available on long distance and is compatible with the different size of debris. On the other hand, it is less efficient and is unavailable in GEO. Contact removal can remove multiple targets and has a short working period but demand rendezvous and complicated control system [42].

To turn toward some theorized systems, there are many proposals regarding ADR technology. One of them is the "space tug" that could grab a massive object such as the upper stage or satellite and then move it to a lower or higher orbit. Another proposed option is to attach the dragging system directly to the piece of debris and consequently de-orbit it. Nevertheless, such techniques are not easily implemented. To make them efficient, they would need to be able to drag more than one piece at a time. This would be more feasible for the GEO-based systems as the orbit comprises of a larger number of dysfunctional satellites located in the same orbital plane [41].

To be more specific, let us briefly introduce an example of the currently developed ADR system proposed by KTH Royal Institute of Technology in Stockholm. The institution conducted a feasibility simulation of the potential ADR technology. Their goal was to develop a satellite system that would be able to *"descent 5 of the biggest space debris from their current orbits into a lower orbit with a maximum lifetime of 25 years."* [43] The pieces of orbital debris that

Table 1
Capturing methods.

Type	Positives	Negatives
Tentacles	Easily tested, higher readiness	Complicated rendezvous, possible bouncing
Single arm	Easily tested, higher readiness	Complicated rendezvous, collision risk, requires grappling point
Multiple arms	Easily tested, flexible capturing	Sophisticated control system, high mass, complicated rendezvous
Net capturing	Large distance, lower precision requirement, usable for different sizes of debris	Hard to control, complicated testing, risk of critical oscillations
Tether gripper	Large distance, low mass, short capture time	Lower reliability, complicated testing, requires grappling point
Harpoon	No grappling point required, larger distance, usable for different types of debris	Risk of fragmentation

were selected for the study were located in the altitudes between 750 and 800 km within the area with the highest density of the orbital debris [43]. A reconstructed Orbit Life Extension Vehicle was selected as the dragging vehicle. The mass of the system would be around 600 kg including "70 kg *of fuel,* 100 kg *in structural mass,* 130 kg *of other maneuvering thrusters and their system,* 20 kg *for the grabbing arm,* 50 kg *of communication command and control systems,* 50 kg *of the solar panels and batteries,* 50 kg *for the electric motor and* 30 kg per *SDK, which is short for Sail Deorbiting Kit.*" [43] As a launcher, SpaceX's Falcon 9 was proposed because of the cost reduction [43]. Authors concluded that "*space debris removal with satellites propelled with electric Hall effect engines and accelerated drag using an expandable foam sail can be implemented with a low cost, high reliability, and high impact.*" [43]

The space-based ADR system will further need to struggle with the effectiveness barrier. Any project needs to be as cheap as possible, and this is mainly connected to the movement on orbits that require the burning of fuel. Utilization of new propulsion systems and precise calculations of the orbital path aiming to decrease the need for maneuvering seem to be the essential steps forward [44]. Also, the capturing methods are useful only regarding large (thus the most pressing) pieces of orbital debris. For the smaller pieces, other systems—laser-based or other similar systems—will need to be developed. There are two possible options for these systems—Earth-based and space-based—with a combination of the two also proposed [45,46]. These systems are, nevertheless, not the primary focus of our study.

Most recently, some of the ADR capabilities are already being tested. The joint project led by Surrey Space Center co-funded by European Commission is currently running a series of experiments of ADR systems involving, alongside with drag sail and vision-based navigation, net, and harpoon experiment [47]. The test should reach a maximum altitude of about 400 km and deploy its practice targets. If successful, it could be an important milestone to ADR missions. The net should catch the 2 kg object 1-m in diameter and will be the first demonstration of its kind. The system is focused on large orbital debris, and the 5-m net should be already capable of capturing the debris in the range of 1,5 m. The harpoon will aim to 10 × 10 cm deployable target in the distance of 1,5 m. The harpoon capture system was chosen for several advantages: low mass and volume enable utilization of multiple harpoons on single aircraft. Furthermore, the harpoon is relatively simple. Thus, low development cost and risk could allow concurrently high reliability. Fast rates spinning objects may be targeted because of high firing speed [48]. In case of success, the practical applicability of ADR would be confirmed.

6. ADR systems as ASAT weapons?

The important questions regarding the utilization of ADR systems are to what degree are they useful as ASAT systems, and how to ensure their applicability in an international environment increasingly characterized by the competition among important space powers. The current level of technological development, as well as the legal framework established for outer space, leads us to a belief that any potential aggressive behavior regarding the space activities will be conducted by utilizing the ASAT weapons. As mentioned earlier, the utilization of the currently tested land-based kinetic impactors, nevertheless, presents a crucial problem that is connected to the creation of a massive debris cloud that follows the successful attack. This was demonstrated by the 2007 Chinese test and effectively decreases the utility of the contemporary ASAT technology [18]. One solution that is currently being used comprises of the cyberattacks on the data flows connecting satellites to the ground infrastructure or blinding of the satellites. Not only does this type of attack enjoys all the advantages of cyberattacks, such as a lack of attribution and plausible deniability, but also its success would not result in an extensive spread of new pieces of orbital debris. The second option is a development of ASAT technology that would incapacitate a satellite without its physical shattering. This can be done either by utilization of the direct-energy systems [18,49,50] or systems similar to the proposed ADR technology. The use of direct-energy systems is hampered by their clear military intent. As the weaponization of outer space operations is not welcomed inside the international arena, their development would probably cause large opposition. The much more viable approach seems to be the utilization of dual-use ADR systems.

As noted above, the currently proposed ADR systems are based on a basic logic stating that a maneuverable asset would get to a vicinity of a large piece of orbital debris and by using specific technology would capture and deorbit it. Given the limited maneuverability of space assets, even functional satellites would probably be unable to escape such an attempt. This means that there is a certain possibility that the operator of the technology might be tempted to misuse it throughout periods of crisis. There are, nonetheless, three main obstacles to effective utilization of the ADR systems as ASAT weapons. The first is legal. Although the international law might be vague, an active and purposeful disruption of the operational satellite would constitute an act of aggression. Second, for an effective disruption of the complex satellite systems, a large presence of ADR satellites would be needed. As noted earlier, it is planned that the ADR systems should deorbit several pieces of debris per year. For example, the GPS constellation consists of 24 satellites with available spares. This means that to make the ADR system an effective weapon system, it would need to establish a much larger constellation than needed by the orbital debris removal proponents. Also, the movement of the vehicle would be rather slow and limited because of the limited amount of fuel it can carry. Any target would thus get plenty of warning time before any potential attack. Third, the misused ADR system might become a target of the land-based ASAT systems that all the major space powers except for Europe operate. As the ASAT systems are efficiently capable of striking objects in LEO, and theoretically even higher orbits, there would be a potential risk of conflict escalation.

The utility of the ADR system as an ASAT weapon rests upon its dual-use capacity. While the land-based ASAT weapons are purely military devices, the ADR systems will face an issue similar to the other examples of the dual-use space technology—the importance of intent. The ADR technology can be utilized as an ASAT system with its limitations as noted earlier. Despite the apparent limitations of the utility of these systems as weapons in a regular point of view, the ADR system can be utilized as a part of space hybrid operations. ADR methods often require advanced rendezvous and proximity operations that can be misused for offensive actions that are, nevertheless, difficult to track down and expose and remain below the threshold of military response.

Any ADR system will, however, be in a spotlight of the space powers, and other means of conducting such operations would probably remain more useful. It, however, presents a key technology necessary for ensuring the sustainability of the space endeavors. The key is thus not to limit the technological progress in the area but to ensure that none of the space actors will see its development as a threat. This calls for either a coordinated effort among the spacefaring nations or the development of the debris removal as a commercial service. Here we return to the issue of intent. While technologically speaking, an ADR system designed to be a non-military object would hold only limited potential as a weapon, the unclear nature of the intent could change the calculations of the spacefaring nations. If the system is being developed by a single country, there exists a potential that all the major space powers will attempt to develop the technology, and in that case, the technology will cross the threshold for effective weaponization.

Given the complicated relationships among the actors like the United States, China, Europe, and Russia, commercialization of the process seems to be a better way forward. Following the development of NewSpace [3,21], it seems highly likely that the private entities will attempt to participate in the newly emerging debris mitigation market as well. This process can be conducted in cooperation with some of the less negatively perceived space agency like the ESA that develops some of the necessary technologies as a part of its Clean Space initiative—namely e.deorbit [5,51]. Commercial actors also do not face the issue of intent as they are profit-oriented unlike the complicated structure of the national interests. The commercialized and cooperative effort together with the presented technological limitations of the utility of the ADR systems as ASAT weapons should ensure that the process of the debris removal will take place without causing unnecessary conflict. The negative perception of the ADR systems can thus be limited by taking several steps: (a) do not develop capacity over the level suggested for an effective debris mitigation as to decrease the technological utility of the ADR systems as weapons, (b) operation of the ADR system should lay in hands of a commercial actor that would be contracted to clear the selected objects either by states or the UN, (c) any technological cooperation with the national space programs should primarily lay in technological development of the systems and not in their management and control —this cooperation should be coordinated at the UN level, and (d) the ADR systems should not act unexpectedly as to increase the trust of all the spacefaring nations in the sincere intent of the operator.

7. Conclusion

The article aimed to assess the utility of the ADR systems as ASAT weapons. While looking at the limitations of the currently operational ASAT weapons, we can identify many advantages that the ADR system would hold if used in a harmful manner. It does not produce additional clouds of orbital debris and is not a military-only technology. Nevertheless, ADR systems carry their own set of restrictions if used as an ASAT weapon, namely limited reach and easy destructibility by kinetic ASAT weapons. This leads us to the consideration that the technology of the ADR system is probably not practical for the conduct of massive ASAT attacks if developed in a scope proposed by the supporters of active debris mitigation. As a dual-use technology, its primary function is, nevertheless, determined by the intent of the owner. If the ADR systems are to be effectively utilized in the civil sector, the actor operating them must be perceived as reliable by the vast majority of the international space community. We think that this will be best done by commercialization of the effort in the context of cooperation with state space agencies operating in the sphere—especially civilian ESA—that might help with the technological development. This support should be done under the coordination by the UN as to decrease the negative perception of the operation of such systems.

Funding

The study was funded by UNCE (University Research Center), UNCE/HUM/037, Human-Machine Nexus and Its Implications for International Order.

References

[1] D.J. Lonsdale, Information Power: strategy, geopolitics, and the fifth dimension, J. Strat. Stud. (1999) 137–157.
[2] R. Liemer, C. Chyba, A verifiable limited test ban for anti-satellite weapons, Wash. Q. 33 (3) (2010) 151–152.
[3] D. Paikowsky, What Is new space? the changing ecosystem of global space activity, New Space (2017) 86.
[4] IADC, IADC Space Debris Mitigation Guidelines, UNOOSA, September 2007, p. 5. http://www.unoosa.org/documents/pdf/spacelaw/sd/IADC-2002-01-IADC-Space_Debris-Guidelines-Revision1.pdf.
[5] R. Biesbrok, Active Debris Removal in Space: How to Clean Earth's Environment for Space Debris, Charlestone: CreateSpace, 2015.
[6] S.-C. Wang, Transatlantic Space Politics: Competition and Cooperation above the Clouds, Routledge, Abingdon, 2013, p. 154.
[7] J. Johnson-Freese, Space Warfare in the 21st Century: Arming the Heavens, Routledge, Abingdon, 2016.
[8] A.J. Tellis, China's military space strategy, Survival 49 (3) (2007) 41–72, https://doi.org/10.1080/00396330701564752.
[9] Y. Zhang, The eagle eyes the dragon in space—a critique, Space Pol. 29 (2) (2013) 113–120, https://doi.org/10.1016/j.spacepol.2013.03.002.
[10] A. Lele, Asian Space Race: Rhetoric or Reality? Springer India, Heidelberg, 2013, pp. 91–92.
[11] J. Johnson-Freese, A new US-Sino space relationship: moving toward cooperation, Astropolitics 4 (2) (2006) 131.
[12] M. Aliberti, When China Goes to the Moon, Springer, Cham, 2015, p. 23.
[13] G. Milowicki, J. Johnson-Freese, Strategic choices: examining the United States military response to the Chinese anti-satellite test, Astropolitics 6 (1) (2008) 1–21, https://doi.org/10.1080/14777620801907913, p.6.
[14] US Air Force, Air Force Doctrine Document 2-2.1, 2004, p. 55. Available at: http://www.space-library.com/0408_afdd2-2.1.pdf. (Accessed 25 September 2016).
[15] https://www.whitehouse.gov/briefings-statements/president-donald-j-trump-unveiling-america-first-national-space-strategy/.
[16] E. Dolman, Astropolitik: Classical Geopolitics in the Space Age, Frank Cass, London, 2005.
[17] M. Martindale, Evaluating state willingness to pursue space weapons, Def. Secur. Anal. 31 (2) (2015) 110–122, https://doi.org/10.1080/14751798.2015.1014159, p.112.
[18] P.L. Hays, Space and Security: A Reference Handbook, Contemporary World Issues Book Series, 2011, p. 30.
[19] J.C. Moltz, The Politics of Space Security: Strategic Restraint and the Pursuit of National Interests, Stanford University Press, Stanford, 2011, p. 261.
[20] V."U.S. Anantatmula, Initiative to place weapons in space: the catalyst for a space-based arms race with China and Russia, Astropolitics (2013) 132–155, p.143.
[21] E. Quintana, The new space age: questions for defence and security, RUSI J. 162 (3) (2017) 88–109.
[22] See https://www.teslarati.com/spacex-starlink-gains-fcc-approval/.
[23] See http://oneweb.world/.
[24] K. Hebert, Regulation of space weapons: ensuring stability and continued use of outer space, Astropolitics 12 (1) (2014) 1–26. Available at: http://www.tandfonline.com/doi/abs/10.1080/14777622.2014.890487 [Accessed 2017-10-22]. P 3.
[25] T. Hitchens, M. Katz-Hyman, J. Lewis, U.S. space WEAPONS, Nonproliferation Rev. 13 (1) (2006) 42–43.
[26] L. Grego, Aegis as ASAT, Union of Concerned Scientists, 2012. Available at: http://allthingsnuclear.org/lgrego/aegis-as-asat. Accessed 2017-03-15.
[27] L. Wood, Russia Tests Anti-satellite Weapon, PL-19 Nudol, The Washington Times, 2016. Available at: http://www.washingtontimes.com/news/2016/dec/21/russia-tests-anti-satellite-weapon-pl-19-nudol/. Accessed 2017-03-16.
[28] K. Mizokami, Russia Tests a New Missile that Can Destroy Orbiting Satellites, Popular Mechanics, 2016. Available at: http://www.popularmechanics.com/military/research/news/a24455/russia-anti-satellite-weapon/. Accessed 2017-03-16.
[29] B. Gertz, Russia Flight Tests Anti-satellite Missile, Washington Free Beacon, 2015. Available at: http://freebeacon.com/national-security/russia-conducts-successful-flight-test-of-anti-satellite-missile/. Accessed 2017-04-15.
[30] B. Gertz, Inside the Ring: Russia Tests ASAT Missile, The Washington Times, 2018. Available at: https://www.washingtontimes.com/news/2018/apr/4/inside-the-ring-russia-tests-asat-missile/. (Accessed 7 April 2018).
[31] Office of the secretary of defense, ANNUAL REPORT TO CONGRESS, Department of Defense, 2013. Available at: https://web.archive.org/web/20150113120816/http://www.defense.gov/pubs/2013_china_report_final.pdf. Accessed 2017-03-16.
[32] B. Weeden, 2007 Chinese Anti - Satellite Test Fact Sheet, Secure World Foundation, 2010, p. 1. Available at: https://swfound.org/media/9550/chinese_asat_fact_sheet_updated_2012.pdf. Accessed 2017-03-16.
[33] V. Mahajan, Chinese anti-satellite means: criticality and vulnerability of Indian satellites, CLAWS J. (2016) 172–188.
[34] Center for Strategic and International Studies, Agni-3 | Missile Threat, Missile Threat, 2016. Available at: https://missilethreat.csis.org/missile/agni-3/. (Accessed 16 March 2017).

[35] P. Duddu, The 10 Longest Range Intercontinental Ballistic Missiles (ICBM), Army Technology, 2013. Available at: http://www.army-technology.com/features/feature-the-10-longest-range-intercontinental-ballistic-missiles-icbm/. (Accessed 16 March 2017).

[36] G. Forden, A Preliminary Analysis of the Chinese ASAT Test, MIT, 2007, pp. 1–30. Available at: http://web.mit.edu/stgs/pdfs/A%20Preliminary%20Analysis%20of%20the%20Chinese%20ASAT%20Test%20handout.pdf [Accessed 2017-04-27. p.29].

[37] S. Kaiser, Viewpoint: Chinese anti-satellite weapons: new power geometry and new legal policy, Astropolitics 6 (3) (2008) 313.

[38] ESA, About Space Debris, European Space Agency, 2013. Available at: http://www.esa.int/Our_Activities/Operations/Space_Debris/About_space_debris. Accessed 2017-10-22.

[39] S. Black, Y. Butt, The growing threat of space debris, Bull. At. Sci. 66 (2) (2010) 3–4.

[40] C. Rajapaksa, J. Wijerathna, Adaptation to space debris mitigation guidelines and space law, Astropolitics 15 (1) (2017) 66.

[41] M. Sorge, G. Peterson, How to Clean Space: Disposal and Active Debris Removal, 2015. Available at: Web.archive.org https://web.archive.org/web/20180303033217/https://aerospace.org/crosslinkmag/fall-2015/how-to-clean-space-disposal-and-active-debris-removal/. Accessed 29 Jun. 2018.

[42] M. Shan, J. Guo, E. Gill, Review and comparison of active space debris capturing and removal methods, Prog. Aero. Sci. 80 (2016) 18–32.

[43] G. Gabriele, M. Alexandru Camil, N. Karl Gustav, B. Antoine, N. Naser, L. Ling, Active space debris removal system, Incas Bulletin 9 (2) (2017) 99.

[44] A. Ruggiero, P. Pergola, M. Andrenucci, Small electric propulsion platform for active space debris removal, IEEE Trans. Plasma Sci. 43 (12) (2015) 4200–4209.

[45] Q. Wen, L. Yang, S. Zhao, Y. Fang, Y. Wang, Removing small scale space debris by using a hybrid ground and space based laser system, Optik Int. J. Light Electron Optic. 141 (2017) 105–113.

[46] S. Scharring, J. Wilken, H. Eckel, Laser-based removal of irregularly shaped space debris, Opt. Eng. 56 (1) (2016) 2.

[47] University of Surrey, RemoveDEBRIS, 2018. Available at: https://www.surrey.ac.uk/surrey-space-centre/missions/removedebris. (Accessed 10 June 2018).

[48] J. Forshaw, G. Aglietti, N. Navarathinam, H. Kadhem, T. Salmon, A. Pisseloup, E. Joffre, T. Chabot, I. Retat, R. Axthelm, S. Barraclough, A. Ratcliffe, C. Bernal, F. Chaumette, A. Pollini, W. Steyn, RemoveDEBRIS: an in-orbit active debris removal demonstration mission, Acta Astronaut. 127 (2016) 448–463.

[49] A. Steinberg, Weapons in space: the need to protect space assets, Astropolitics 10 (3) (2012) 248–267, https://doi.org/10.1080/14777622.2012.733867.

[50] V. Dvorkin, Space weapons programs, in: A. Arbatov, V. Dvorkin (Eds.), Outer Space: Weapons, Diplomacy, and Security vols. 30–45, Carnegie Endowment for International Peace, Washington DC, 2010, pp. 35–36.

[51] ESA, ESA and Space Debris, March 2013. http://esamultimedia.esa.int/multimedia/publications/BR-309/. (Accessed 2 May 2016).