Acta Astronautica 187 (2021) 397–405

Contents lists available at ScienceDirect

Acta Astronautica

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

Dual-use conundrum: Towards the weaponization of outer space?

Jakub Pražák

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

ARTICLE INFO

Keywords:
Dual-use
Space weapon
Space warfare
ASAT
Space security

ABSTRACT

The accumulating tensions between major space powers increase the likelihood of space conflict. Though outer space is widely militarized, presumably it has not been weaponized. However, the dual-use nature of space technology raises serious concerns about its utilization. The article reviews and compares chosen space systems and technology with the residual offensive capability that could be misused for malicious purposes and could be utilized as space weapons. Demonstrated space-related technology, namely space launch vehicles, small satellites, satellites as weapon platforms, information technology and active debris removal systems, have broad dual-use consequences that can eventually lead to the weaponization of outer space. Nevertheless, space conflict would most likely result in undesired proliferation of space debris with irreversible impact on space environment. The states should promote responsible behaviour concerning emerging space technology and should seek further consideration of space norms that would sustain peaceful uses of outer space.

1. Introduction

The outer space is a contested, congested and competitive strategic domain. Contested due to the increased number of spacefaring nations that are willing to develop and proliferate counterspace capabilities; congested because of the rising number of space debris; and competitive, given by the increased share of state and commercial actors on the space market [1]. Hence, space relations confront many challenges that may undermine the peaceful uses of outer space. According to Johnson-Freese, 95% of space technology have both military and civilian application [2]. Though outer space is widely militarized, presumably it has not been weaponized. However, as Johnson-Freese pointed out, contested outer space environment may easily result in aggressive, zero-sum behaviour of spacefaring nations. Many militaries presume the inevitability of space warfare that only supports research and development of counterspace capabilities [3]. The dual-use nature of space technology challenges the proliferation of space weapons and raise serious concerns about its utilization. The article elaborates on malicious utilization of dual-use space technology and its prospects of exploitation as space weapons. Even the primarily non-weapon related technology can be converted and embrace their destructive potential for the space environment. The central argument of the article claims that space technology may be misused for offensive purposes and encourage space weaponization that may have severe consequences for space relations and environment.

The article reviews and compares chosen space systems and technology with the residual offensive capability that could be misused for malicious purposes and could be utilized as space weapons. The article at first presents the theoretical background of space warfare strategy and opportunities for major space powers for military conquest, followed by the dual-use technology debate with emphasis on the development of counterspace technology and space weapons. Subsequently, the article discusses the prospects of space technology as space weapons, explicitly dealing with space launch vehicles, small satellites, satellites as weapon platforms, information technology, and active debris removal systems. Finally, the article will elaborate on its implications for space relations and peaceful uses of outer space. The selected examples of dual-use technology were chosen for their relevance to current dynamics and notions in space security and sufficient quantity of available sources that could be discussed for their assessment. It should be noted that states often classify the detailed information related to space technology and for academic purposes, the author had to work with accessible and declassified documents. The article demonstrates that discussed space technology can be misapplied to attack adversary's space assets. The findings call for international responsibility for the development and utilization of dual-use space technology. International community should further consider the possibility of war in space and review the existing treaties regarding space weapons and set clear rules for the application of dual-use technology. Otherwise, dual-use space weapons could become a part of counterspace or space warfare strategy hazarding with space safety and protection of the outer space environment.

E-mail address: jakub.prazak@fsv.cuni.cz.

https://doi.org/10.1016/j.actaastro.2020.12.051
Received 1 April 2020; Received in revised form 2 November 2020; Accepted 28 December 2020
Available online 5 January 2021
0094-5765/© 2021 IAA. Published by Elsevier Ltd. All rights reserved.

2. Realist paradigm of outer space

Outer space is an independent strategic domain with increasing importance. NATO proclaimed outer space as a new operational domain in November 2019, alongside air, land, sea, and cyber to enhance cooperation and share of capabilities [4]. However, the space environment shares certain analogies to traditional domains. Space has its distinguished Lines of Communication, Common Routes, Choke Points, or Harbor Accesses that may be exploited for space dominance [5]. Alfred Thayer Mahan observed it is impossible to occupy all the seas and oceans, nevertheless, it is possible to choose the strategy based on the control over chokepoints and strategic locations with only the limited amount of forces and resources. Outer space provides similar opportunities. For instance, Low Earth orbit or geostationary orbit may be deemed as critical space locations. Hohmann transfer orbit can be then regarded as a common route since it utilized for a two-phase manoeuvre to transit into a higher orbit. Accordingly, it was illustrated that space conquest might be a difficult but plausible task to achieve. Notwithstanding, it must be acknowledged three-dimensional movement of high velocities and global nature of space operations magnify its complexity, namely concerning propulsion requirements for overcome gravity wells of space objects [6].

Dolman [7] claims there is a scarcity of coherent space strategies, despite the significant interest in space domination since 1946. Already in 1961, the astronomical community agreed that outer space consists of strategic locations that could be compared to the strategic importance of the Panama Canal. In 1991, Arthur C. Clarke referred to the Gulf War as *"the world's first satellite war."* [8] Though such a claim may sound fairly exaggerated that time, the space systems considerably developed and functions that were underestimated a few decades ago such as navigation, communication, commercial imaging or weather prediction are nowadays indispensable. Military operations are dependent on space technology and provide important Command, Control, Communications and Intelligence (C3I) and other mission support. Already at the very beginning of our millennia, Dolman argued that *"(…) space warfare has emerged from its embryonic stage and is now fully in its infancy."* [6] 20 years later, Bowen [9] concluded that *"[s]pacepower's time has come"* and meaningful space strike can open conflict to provide an advantage for terrestrial forces.

The space relations and peaceful uses of outer space are currently characterized by two distinguished shifts – (1) the conflictual nature of major space powers is well projected in recent development in space rivalry and (2) emergence of New Space featured by growing commercialization of space sector. Though the end of the Cold War brought a decade of seemingly peaceful space development during the 1990s, the new millennium increased Sino-American competition challenging the U.S. space hegemony. China conducted a successful anti-satellite (ASAT) test in 2007, resulting not only in the new era of weapon development but also in the unprecedented proliferation of space debris. The U.S. sealed their space dominance a year later in 2008 by de-orbiting their USA-193 satellite using modified Standard Missile-3 (SM-3) as an ASAT and thus continued their ASAT tests that were halted in 1985. Albeit the official claim was to prevent contamination from 454-kg hydrazine tank attached to the satellite in case it survived re-entry, it was also a clear statement of the U.S. willingness to use power in space [10]. Concurrently, other major space powers do not wish to be disadvantaged, Russia possesses ASAT technology with LEO operability and employs advanced electronic and cyber capabilities [11] and India conducted a successful ASAT test in March 2019 [12]. The willingness of states to protect their space assets is reflected in the space policies. In 2019, the U.S. established Space Force as a sixth branch of the military [13], re-activated the U.S. Space Command and recognized space as a warfighting domain in reaction to Chinese and Russian development of kinetic and electronic weapons [14,15]. Other spacefaring nations similarly realize the need to protect their space assets. In 2020, Japan instituted Space Domain Mission Unit (SDMU) as a part of Japan's Air Self-Defense Force. SDMU should be fully operational by 2022 and will have under direction space situational awareness and protection of Japanese satellites via counterspace capabilities [26]. France intends to deploy small bodyguard satellites with cameras and presumably defensive weapons by 2023 [16] and a new generation of Syracuse satellites with capabilities to detect and disable[1] enemy space satellites by 2030 [17]. Norway's two satellites that are planned to be deployed in 2022 to provide broadband coverage over strategic Arctic region will likely carry anti-jamming, anti-radiation and other enhanced protective measures against interference [18]. The second important point is the emergence of so-called New Space. The new commercial actors are penetrating space business and introducing new technological developments. Though they are driven by profit and making space technology cheaper, at the same moment, the growing number of satellites magnifies the threat of deployment of potentially hazardous dual-use technology [10].

3. Dual-use and space weapon conundrum

U.S. Department of Defence (DoD) defines dual-use technology as *"(…) a technology, that has both military utility and sufficient commercial potential to* support *a viable industrial base."* [19] Until the end of the Cold War, the U.S. space industry was divided into four sectors – military, intelligence, civilian, and commercial. However, after the Cold War use of space evolved and expanded, the traditional silos separating military space and commercial/civil space blurred. Moreover, the role of the commercial sector changed rapidly during recent years and got significant importance. Specifically, in the case of the U.S., the government does not need to invest in technologies that were already researched and development by commercial actors. For that, the U.S. government established the Dual Use Science and Technology program to ensure its access to dual-use technology and both government and military are dependant to commercial technology. On the other hand, commercial technology is available to many other customers and actors. For example, during Operation Iraqi Freedom, Saddam Hussein obtained Russian-made jamming equipment on the Internet and utilized it against the U.S [19]. Global Navigation Satellite Systems (GNSS) is an essential strategic dual-use asset. Both American GPS and Russian GLONASS are exploited for both military and civilian purposes [20]. Navigation satellites can guide civilian airliners as well as munition with precision accuracy and serve as a force multiplier for ground military operations. Though some dual-use capabilities are evident – military rockets, launchers and missiles are based on the same basis as a technology for space flights, some distinctions are less noticeable. For example, the Soviet Union perceived American space shuttles as potential weapons that could conduct rendezvous and proximity operation to destroy the Soviet satellites with a robotic arm or similar device. Johnson-Freese concluded only the planet and solar physics research has apparent civil utilization. Nevertheless, even this technology may have military implications in the future [19].

Considering the prospects of space weapons, Karl Hebert delimits a space weapon as *"any asset, Earth-based or space-based, designed to attack targets in space (Earth-to-space and space-to-space). Space weapons also include space-based assets designed to attack targets on Earth. For this definition, space-based weapons include weapons placed on celestial bodies."* [21] In this connection, Hitchens, Katz-Hyman and Lewis mentioning the possible development of space-to-Earth weapons and technology, specifically space-based missile defences and space-based strike capabilities [22]. Krepon and Katz-Hyman argue while outer space has been militarized, no space weapons are currently deployed in outer space, thus, it is not weaponized. However, they also mentioned some authors claim otherwise when referring to "residual" or "latent" space warfare

[1] Upgraded version of Syracuse satellite should carry lasers or submachine guns with the capability to disable or destroy enemy satellites.

capabilities (e.g. inter-continental ballistic missiles that briefly penetrate outer space) that did not turn into space warfare actuality. Eventually, they *"(…) define space weapons and offensive space warfare initiatives as terrestrially based devices specifically designed and flight-tested to physically attack, impair, or destroy objects in space, or space-based devices designed and flight-tested to attack, impair, or destroy objects in space or on earth. This definition respects the distinction between capability and actuality. It excludes residual or latent space warfare capabilities, such as ballistic missiles. Also excluded in this working definition are satellites that provide essential military functions but do not serve as weapon platforms."* [23] To mention, in their definition, they expelled uplinks and downlinks interference. Accordingly, definition by Krepon and Katz-Hyman, however, do not reflect the reality of space technology development and in essence, excludes the destructive potential of dual-use technology, thus, definition by Hebert provides a better explanation for the malicious uses of dual-use technology. As Harrison and his colleagues pointed out, *"[d]ue to the dual-use nature of many space technologies, even benign space capabilities can be viewed by others as counterspace weapons."* [11].

It should be noted that the definition of space weapon can be very flexible in meaning. The draft of the "Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force against Outer Space Objects" proposed by Russia and China aims to forbid the placement of weapons in outer space, however, the treaty consider as space weapon only "weapon in outer space" that is defined as *"any outer space object or its component produced or converted to eliminate, damage or disrupt normal functioning of objects in outer space, on the Earth's surface or in the air, as well as to eliminate population, components of biosphere important to human existence, or to inflict damage to them by using any principles of physics."* [24] Nevertheless, such definition excludes all the ground-based systems, including direct-ascent (DA) ASAT weapons and thus justifying their further development.

Space hybrid operations conducted in the "grey zone" spectrum constitute a potential threat and are often based on dual-use capabilities. Robinson et al. defined space hybrid operations as *"intentional, temporary, mostly reversible, and often harmful space actions/activities specifically designed to exploit the links to other domains and conducted just below the threshold of requiring meaningful military or political retaliatory responses."* [25] Robinson et al. [25] divided space hybrid operations into five categories – (1) directed energy operations that may result in space debris; (2) orbital operations that generally do not result in space debris; (3) electronic operations; (4) cyber operations; (5) and economic and financial operations (E&F). By directed energy operations that may result in space debris is understood low-power laser dazzling or blinding, high-power microwave (HPM) or ultrawideband (UWB) emitters. Altogether with electronic and cyber operations, they can be considered as counterspace capabilities that serve as potential weapons [11,26]. Orbital operations that generally do not result in space debris are space object tracking and identification and rendezvous and proximity operations (RPO). In this context, it is fundamental to highlight the dual-use capabilities involving RPO and active debris removal system (ADR). *"ADR systems are a good example of how space assets can be utilized for both, benign and aggressive actions. These systems are purposed to remove a dysfunctional space object by using another spacecraft. That, however, means that they can also be used for removal of, or interference with, a functional system."* [25]. Authors argue that ADR systems have many things in common with RPO and can be exploited for offensive purposes. Besides, space systems are not sufficiently protected and can be easily compromised [25]. E&F operations are malicious economic and financial activities that aim to "space sector capture" defined as *"a state actor's provision of space-related equipment, technology, services and financing ultimately designed to limit the freedom of action and independence of the recipient state's space sector, generally implemented on an incremental basis."* China and Russia both used "space sector capture" activities to gain an advantage over adversaries by economic means [25]. Albeit such operations cannot be classified as space weapons, they possess a challenge for a proliferation of dual-use technology. The states would not be keen to supply their adversaries with sensitive dual-use technology [27] and conversely, states should secure reliable space technology suppliers since the hardware and software products can be utilized for cyber espionage [26].

4. Dual-use technology as space weapons

Dual-use technology is, in essence, not a weapon. However, some dual-use systems dispose of a technology that may be misused for the space weaponization. The article focuses on several specific systems that are either widely proliferated or emerging and are expected to be a challenge for space security soon. The article discusses the offensive potential of following systems – launch vehicles, satellites as weapons platforms, small satellites, information technology, and active debris removal systems.

4.1. Space launch vehicles

The launch vehicles for the transportation of satellites and other payloads in orbit are the major potential threat to other systems since they have many in common with ballistic missiles and missile defence interceptors that can be modified into kinetic ASAT weapons [11]. That was highlighted by the fact that launch vehicles are of concern of non-proliferation ballistic missiles agenda and there are close interconnections between ballistic missiles and space launch vehicles programs [28]. The Hague Code of Conduct against Ballistic Missile Proliferation that was established in November 2002 that was signed by 139 states [29] directly refers to the space launch vehicles and states that *"Space Launch Vehicle programmes should not be used to conceal Ballistic Missile programmes''* [30]. Mistry and Gopalaswamy [28] concluded that *"space launchers being used as ballistic missiles and ballistic missiles being used as space launch vehicles or even as anti-satellite systems—should not be ignored by analysts and policy makers."* The U.S. is repeatedly accused Iran of using space launches for testing ballistic missile technology [81]. Moreover, dual-use industrial technology can be transferred from the civilian sector to ballistic missiles. For instance, Indian solid-fuel production plant was exploited for both civilian space launchers and Agni missiles production [28].

It would be rather easy to proliferate kinetic ASAT capabilities based on existing missiles. China conducted a successful ASAT test in 2007 by SC-19 DA ASAT weapons launched from a mobile Transporter–Erector–Launcher (TEL) from a pad at Xichang. The launch vehicle for this test was derived from DF-21 Intermediate-Range Ballistic Missile and kinetic kill vehicle based on HQ-19 long-range Surface-to-Air Missile (SAM) system that was supported by active radar or passive multispectral Infra-Red homing guidance, or both. Such a weapon can efficiently operate in LEO. In 2013, China launched the new DA-ASAT labelled as Dong Ning-2 (DN-2) from TEL at Xichang. The multistage rocket was based on the Kuaizhou commercial satellite launch vehicle that has its basis in already mentioned DF-21C and was proposed by the same entity. This weapon reaches an altitude about 10 000 km, however, an apogee of this rocket was estimated to approximately 30 000 km and with some development and previously tested kinetic kill vehicle could endanger satellites even in GEO [31]. This shows clear linkages between peaceful and offensive capabilities. It is fair to say the next challenge for DA ASAT development is the construction of an advanced kinetic kill vehicle. Specialized guidance software, seekers, and thrusters on kinetic kill vehicles do not have such dubious dual-use applications. China has twice failed to intercept the target before the successful test in 2007, nevertheless, in the case of China, further testing likely enhanced these capabilities [77].

Furthermore, the blurred design of intercontinental ballistic missiles and launch technology could be misused for the delivery of not only kinetic but also weapons of mass destruction that could be of interest for North Korea. In 2016, the United Nations Security Council denounced

North Korea of testing missiles that could reach the U.S. mainland. On the other hand, North Korea claimed the intention was only to deliver observation satellite into orbit. Mistry and Gopalaswamy mentioned a similar example from 2012, which both demonstrates the ambiguity of space launch vehicles problematics [28,34].

Finally, space launch vehicles may serve as a delivery system for space weapons. This issue could make connections between civilian and military more complex since private actors are exploited for the state's military contracts. SpaceX President and Chief Operating Officer Gwynne Shotwell even expressed the will to potentially deliver U.S. military weapons into space and raised concerns about the space activities of China and Russia [32,33].

4.2. Small satellites

The small satellites (small sats) are generally considered satellites with the weight lower than 500 kg. The subcategories of small satellites are then (1) mini satellites (100–500 kg); (2) micro satellites (10–100 kg); (3) nano satellites (1–10 kg); (4) pico satellites (0,1–1 kg); and (5) fenito satellites (less than 100 g) [35,36]. The emerge of so-called NewSpace characterized by the commercialization of the space sector will dramatically increase the numbers of satellites with the production of advanced cheap small satellites technology and the deployment of satellite mega-constellations [37,38]. There are currently over 2700 functional satellites orbiting around the Earth [39]. However, there are plans to deploy over 100 000 new satellites during the next decade [82]. For instance, SpaceX company intends to launch more than 40 000 small sats for their Starlink mega constellation to provide unlimited internet coverage [40]. Similar projects will increase the density of space traffic and will require advanced space situational awareness and space traffic management. However, the real issue given by the dual-use nature of space technology is the utilization of small satellites as co-orbital space weapons. As Straub pointed out, *"[w]hen a $5000 satellite can potentially damage a $50 million one, there is not a parity of risk levels: the less expensive craft's operator may be more prone to taking risks that may result in peril to the more expensive craft."* [35] Furthermore, compact propulsion systems especially designed for small sats are under development [41]. Such systems may be essential for the future safety of space traffic but may also increase insecurities about dual-use threats. Besides, a special category of small sats that would endanger space activities can be the deployment of space mines that would protect strategic space regions or assets [42].

Rendezvous and proximity operations are an excellent example of how small sats might be exploited. RPOs can be utilized for peaceful civilian operations as well as for malicious or even offensive activity. While not being a small sat itself, Russia conducted various orbital manoeuvres for inspectional purposes and serves as an example of mischievous RPOs. Practically speaking, in 2014, the U.S. airmen observed that Russian satellite designated as Kosmos 2499 that was previously deemed as space debris was unexpectedly spotted active conducting advanced proximity manoeuvre to inspect the rocket booster. Russian Kosmos 2499 satellite is believed to be the actual space weapon with capacities to destroy other targets. A similar case is the Russian Luch satellite that was spying in geosynchronous orbit with latent destructive potential [43,44]. Lately, in January 2020, two Russian satellites with likely inspection capability, Kosmos 2542 and Kosmos 2543 were spotted at a short distance from the American USA-245 reconnaissance satellite [45]. Nevertheless, the scope of small sats capabilities may be more extensive. The Chinese conducted many RPOs to their satellites, probably testing dual-use counterspace technology [78] and in 2008 also approached International Space Station with its BX-1 miniature imaging satellite, potentially simulating co-orbital strike. It is also worth noting that the China tested grappling arms that could serve as efficient ASAT capabilities [11,43,46–49] and the U.S. is testing classified experimental X–37B reusable spacecraft with manoeuvring capabilities and cargo space for potential counterspace equipment or small sats. Moreover, American microsatellites XSS-11 and MiTEx are constructed for advanced RPOs and could serve as potential co-orbital weapons [43,50–52].

It is difficult to distinguish which RPOs and satellites are tested for peaceful, offensive, or both purposes. However, although the detailed sources of malicious space activities may be classified and thus unclear, it is the matter of fact that all the United States, Russia and China conducted various rendezvous and proximity operations and possess the capability to develop and deploy co-orbital ASAT weapons in both LEO and GEO [26]. The New Space era with hundreds of thousands of new space system will arguably increase uncertainty about their malicious utilization.

4.3. Satellites as weapon platforms

In 1974, the Soviet Salyut 3/Almaz military reconnaissance space station contained modified 23 mm Nudelman cannon that reportedly proved to be operational in the space environment [53]. However, its practical utility was never accomplished. Probably the most notorious project to place weapons in space is Reagan's Strategic Defense Initiative (SDI). In the 1980s, American president Reagan believed that space-based anti-ballistic missiles interceptors could protect the United States and make Soviet nuclear ballistic missiles inefficient. However, this so-called "Star Wars" project was technologically unfeasible since it required the development of more advanced technology that was unknown at that time. The initiative proposed many systems that involved space and ground-based lasers or missiles and tracking systems. Although the funding of the initiative was rapidly cut in the early 1990s and the project was never realized [54].

In 2003, Spacy II [55] wrote an article "Assessing the military utility of space-based weapons" referring to the feasibility of space-based weapons. He argued technological immaturity and costs of space-based systems would make the proliferation of space-based weapons in the next 15–20 years inefficient (but not impossible) and that ASAT capabilities will be preferably sent from the ground. He was right in his assumptions, however, his analysis was mostly based on the systems addressing the proposals and costs of SDI. Moreover, he made his conclusions for the 15–20 years continuum that has practically elapsed and the technology progressed. It is difficult to estimate the status of the current space-based capabilities while the detailed information is classified and no weapons are most likely deployed in outer space, however, the critical issue for a space-based weapon is to create a device that would be both powerful and miniatured enough. U.S. Missile Defense Review from 2019 addresses to space-based missile interceptors and provides further details about available capabilities. The document states that the U.S. Department of Defense *"… will undertake a new and near-term examination of the concepts and technology for space-based defences. This examination may include on-orbit experiments and demonstrations. New DoD[2] analysis will evaluate the possible effectiveness of space-based interceptor technologies and their cost-effectiveness when compared to other systems based on the land, sea, and in the air."* [56] The Review focused not only on space-based interceptors but also on space-based sensors and related technology. Specifically, it claims that *"[d]eveloping scalable, efficient, and compact high energy laser technology, and integrating it onto an airborne platform holds the potential to provide a future cost-effective capability to destroy boosting missiles in the early part of the trajectory"* and that *"MDA[3] is developing a Low-Power Laser Demonstrator to evaluate the technologies necessary for mounting a laser on an unmanned airborne platform to track and destroy missiles in their boost-phase."* [56] Moreover, the text mentions the Multi-Object Kill Vehicle (MOKV) program – *"next generation kinetic kill vehicle for the GBI[4]*

[2] Department of Defense.

[3] Missile Defense Agency.

[4] Ground Based Interceptors.

designed to improve the ability to engage ICBM[5] warheads, decoys, and countermeasures using a single defensive interceptor." [56] Notably, tactical aircraft F-35 Lightning II can track and destroy incoming cruise missiles and could be in the future deployed with systems to destroy ballistic missiles in their boost phase [56]. Development of such technology demonstrates the shifts in potentially hazardous dual-use technology. The U.S. Aegis ballistic missile defence system can be used as an ASAT weapon [83].

Overall, the above-mentioned technology can be potentially utilized for the construction of space-based weapons systems that could serve not only as ballistic missiles interceptors but also to target other space systems by both kinetic and non-kinetic means. It is worth noting that the former American Under Secretary of Defense for Research and Engineering Michael Griffin does not perceive space-based ballistic missiles interceptors as a technological problem but as a policy-making decision. Moreover, he expressed his will to research directed energy space-based defence systems and possibly deploy anti-ballistic missile space-based laser by late 2020s [57–59]. In the case of electronic warfare, the China Electronic Technology Group Corporation suggested producing small satellites with jammers to disrupt the U.S. satellite communications [11] that would exploit already discussed small satellites as weapon platforms. Previously mentioned contemporary French efforts then directly aim to construct laser satellites.

4.4. Information technology

Information technology allows access to the cyberspace domain. Space commercialization and development of new generations of satellites are connected to the advancement in communications, transmissions, electronics, computing, or artificial intelligence and process a large amount of data [60]. However, cyberspace can be compromised by an enemy entity. Cyberweapons *"use software and network techniques to compromise, control, interfere or destroy computer systems."* [26] States and military recognize the importance and possible vulnerabilities of cyberspace. In 2016, at the Warsaw Summit NATO acknowledged cyberspace as an independent strategic domain that needs to be protected [61]. The summary of U.S. cyber strategy explicitly states that the U.S. is *"engaged in a long-term strategic competition with China and Russia"* and regards as a vital to *"ensure the U.S. military's ability to fight and win wars in any domain, including cyberspace."* [62]

Cyber operations are among space hybrid threats with difficult attribution. Example of malicious space cyber operation is attack of Russian-led Turla group, which managed to gain access into satellites and stole confidential information about Western embassies, government institutions, and military entities between 2008 and 2016 [25].

Nevertheless, cyber operations or cyberattacks may cause more severe damage. It is important to note that space and cyberspace domain are linked operationally and *"[c]yberattacks will probably represent the preferred offensive strategies when the objective will be to disrupt an entire space system."* [63] So-called advanced persistent threat (APT) attack aims to gain extended access to a system, permanent and undetected capacity to access system information or even take control of the system [63]. Samson and Weeden argued *"[c]yber weapons offer tremendous utility as both a situational replacement for and complement to conventional counter-space capabilities."* [26] The options of a cyberattack may vary from theft or denial of information to control or destruction of satellites, their subcomponents, or supporting infrastructure. Moreover, the commercial space sector is not sufficiently cyber-protected and hardened. As mentioned, in 2008, Iridium communication company and client to Pentagon reportedly publicly bragged about the quality of their cyber satellite resilience. Immediately, a group of hackers eavesdropped Iridium traffic with basic and cheap equipment. The main advantages of cyber-attacks are their flexibility in access and effects, costs, and difficult attribution [26].

With the emergence of New Space, an increased number of space systems will be a plausible target of a cyberattack. While the military sector considers cyber vulnerabilities, some start-up and academia missions are not designed to face cyber threats and may thus be easily compromised. Especially open-source components represent a window of opportunity for malicious actors [80].

Overall, cyberspace can be exploited for offensive cyber operations and thus be considered as a mean of space warfare. Cyberattacks can be used for hybrid operations and interfere with information being sent to/from the satellite. Cyberattacks can also potentially take over or disrupt satellites and thus may be classified as efficient space weapon with both kinetic and non-kinetic impact. In case the attack overtakes propulsion systems, the satellite will not only be lost but will also become a threat to other space systems.

4.5. Active debris removal systems

Active debris removal (ADR) systems are the example of a new emerging space technology that is vital for maintaining access to outer space. As Doboš and Pražák [10] pointed out, *"ADR systems aim to dislocate a dysfunctional system from the orbit disregarding previous consideration about their removal."* However, at the same time, it is also an example of a potential space weapon in case of removal of functional systems. Albeit various methods of ADR systems are being considered, some of them, such as laser technology, are not mature enough to be applied. On the other hand, kinetic options could soon become a feasible solution. There are stiff and flexible principles of kinetic ADR systems. Stiff methods include tentacles, single-arm, multiple arms, and mechanical effector. Flexible connection incorporates net capturing, tether-gripper, and harpoon mechanism. Each method has its positives and drawbacks, thus, the practical application requires a detailed evaluation of their availability and costs. Many proposals and specific drafts of ADR missions have been considered. For instance, the Japanese Astroscale company aims to eliminate some debris in late 2020 and Swiss ClearSpace pursues the same goal by 2025 [84,85]. Nevertheless, when using the ADR system, it is most desirable to de-orbit as many pieces as possible to reduce the costs. For instance, KTH Royal Institute of Technology in Stockholm proposed a mission to de-orbit five debris pieces within the high density of debris in an altitude between 750 and 800 km with the emphasis on affordability, reliability, and impact. For the launch, SpaceX's Falcon 9 rocket was proposed as a most convenient launch vehicle [10]. However, all of the proposed methods, in the case of their proven capability, can also be exploited for malicious purposes or/and as space weapons. During late 2018 and early 2019, a joint project led by University of Surrey tested space reconnaissance and navigation technology, with subsequent tests of net capturing and harpoon methods in the space environment [64–66]. That proved the practical availability of ADR [10] and, thus, the practical existence of a new space weapon.

Although the mentioned net capturing test is presented as a *"first demonstration in the human history of active debris removal technology,"* [85] it is essential to emphasise that the states had already conducted many space tests and operations related to the ADR or space weapon technology. For example, in 2016, China launched Aolong-1 (AL-1) small satellite, also known as the Advanced Debris Removal Vehicle (ADRV) or "Roaming Dragon," that reportedly utilized robotic arm for the removal of space debris [26]. The main advantage of ADR systems as space weapons rests upon their dual-use capability and uncertain intentions. Thus, the target would not have a chance to escape the unsuspected attack. Moreover, the principle of ADR would allow disposing of the enemy satellite without the proliferation of additional space debris. Besides, ADR systems could be utilized for hybrid operations involving rendezvous and proximity operations under the threshold of military conflict.

On the other hand, since ADR aims to de-orbit only several pieces of

[5] Intercontinental ballistic missile.

debris per single mission, to cause appreciable damage to the adversary, a considerable number of ADR systems must be deployed. Secondly, the attack would most likely result in a military response and Earth-based ASAT kinetic weapons could be used to target space-based offensive ADR systems [10]. Nevertheless, the development of ADR systems is forthcoming and necessary for open access to outer space. Doboš and Pražák argued [10] further commercialization of space sector could enhance the peaceful uses of ADR systems, however, as was suggested above, there is also a potential risk of collaboration between the private companies and the state in proliferation of space weapons, in which case the impact would be reversed, and space weapons could become even more affordable. In this regard, the Consortium for Execution of Rendezvous and Servicing Operations is an industry-led initiative which aims to promote best practices and formulate standards for on-orbit services and RPOs to sustain a safe space environment [79].

5. Implications of dual-use weaponry

The further proliferation of potentially hazardous dual-use technology will have a significant impact on the space security and safety of space travel. The final chapter of the article outlines and explains the crucial implications originating in the realist paradigm and conflictual nature of international relations concerning prospects of weaponized outer space.

5.1. Space weapon disorder

In 1963 entered into force the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, also known as the Partial Test Ban Treaty (PTBT) or the Limited Test Ban Treaty (LTBT). The treaty was a reaction to increased nuclear testing that took place also in outer space starting in 1958 by the United States. In 1962, the U. S. conducted the Starfish Prime nuclear experiment at an altitude of 400 km with an explosive yield of 1,4 megatons. An electromagnetic pulse resulting from the nuclear explosion affected satellites, disrupted communication and even blew fuses in Hawaii. Although the treaty banned the testing of nuclear weapons in outer space, it did not focus directly on the regulation of space weapons [21].

The milestone for space law was achieved in 1967 by the adoption of Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies; or shortly Outer Space Treaty (OST). The treaty set the basic norms of international space law and was the basis for later treaties. Though the treaty is not focused restrictively on space weapon regulation, article IV outlines what we may consider as an effort of the arms control in outer space [21]:

"States Parties to the Treaty undertake not to place in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction, install such weapons on celestial bodies, or station such weapons in outer space in any other manner.

The Moon and other celestial bodies shall be used by all States Parties to the Treaty exclusively for peaceful purposes. The establishment of military bases, installations and fortifications, the testing of any type of weapons and the conduct of military manoeuvres on celestial bodies shall be forbidden. The use of military personnel for scientific research or any other peaceful purposes shall not be prohibited. The use of any equipment or facility necessary for peaceful exploration of the Moon and other celestial bodies shall also not be prohibited." [67]

However, the formulation has significant drawbacks. Outer Space Treaty does not provide any definition especially for a term of "peaceful" and what is meant by weapons of mass destruction (WMD). Generally speaking, WMD are nuclear, radiological, biological, and chemical weapons. Thus, other kinds of space weapons are allowed. The term "peaceful" is similarly vague. The U.S. defines "peaceful" as non-aggressive, therefore, it does not limit further space militarization. Moreover, the second paragraph refers to the "Moon and other celestial bodies", though, it does not address to the near-Earth orbit in which the satellites operate [21].

Another treaty, the Anti-Ballistic Missile Treaty (ABM) between the U.S. and Soviet Union from 1972 permitted research but restricted the development and testing of anti-ballistic missile defence components, notwithstanding that in reality, already in 1985, Reagan Administration proclaimed ABM does not limit the Strategic Defence Initiative and the U.S. are allowed to test advanced space-based weapons. However, ABM put no restrictions on ASAT development, thus, it did not regulate the space weapons themselves. Moreover, the U.S. withdrew from the treaty in 2002 [68].

In 2011, The Institute for Security and Cooperation in Outer Space (ISCOS) proposed the Outer Space Security and Development Treaty that intends to limit the utilization of space weapons. Notwithstanding, the treaty has no signatories and again fail to address the term "peaceful". Therefore, deterrent space-based weapons could be justified. Also, the treaty wanted to ban space-based weapons but do not restrict militarization or Earth-based space weapons. The treaty proposed the establishment of the UN Peace in Space Office as an oversight body but questioned its ability to successfully monitor the obligations [21].

The last treaty that attempts to regulate space weapons started in 2008 by the draft of the Treaty on Prevention of the Placement of Weapons in Outer Space (PPWT) proposed by China and Russia. The treaty provides definitions of space weapons, use of force, and the threat of the use of force and aims to ban all space-based weapons. Nevertheless, it does not provide verification tools and does not restrict ground-based systems and weaponry [21]. Hebert suggested that the treaty was purposely proposed 13 months after the Chinese ASAT test that raised concerns about space weaponization and should intimidate the U.S. to sign the treaty [21], though, the U.S. opposed the treaty, among others because China would still be allowed to develop further ground-based ASAT capabilities [69]. The same is the case of Russia who promotes the treaty, however, at the same time is still active in Earth-based ASAT research and development. The air-borne ASAT laser Eshelon for A-50 or A-60 Beriev and kinetic ASAT deployed on Mig-31 are likely receiving funding. Moreover, Russia repeatedly conducted successful tests with the PL-19 Nudol missile interceptor that is at the same time an LEO ASAT [11,70]. To mention, the new draft was presented in 2014, failing to fix the flaws. Interestingly, the treaty would only complicate issues regarding the thesis. According to the treaty, the states could comply with ADR systems as space weapons without the consideration of its legitimacy [71].

To conclude, regulation of space weapons incorporates only the weapons of mass destruction, nevertheless, it should be noted space weapons are not generally banned, moreover, the utilization of nuclear weapons would be inconvenient for the space warfare since it will most likely destroy allied systems. The French initiative to deploy satellites with offensive capabilities emphasises the insufficient legal framework for peaceful uses of outer space and space weaponization. Law regulating space weapons was formulated in the context of the Cold War and do not reflect the new technology development. The international community should promote the establishment of international norms that would respect the current trends in space technology development. In that respect, Woomera and MILAMOS[6] are initiatives focusing on formulation and clarification of rules applicable to military use of outer space [86,87].

5.2. Towards space warfare?

In principle, launch vehicles are resting kinetic ASAT weapons or missile interceptor that can be both deployed for the destruction of space systems. Moreover, launch vehicles are the facilitator of space weapon delivery in outer space. Small satellites are the emerging phenomena

[6] Manual on International Law Applicable to Military Uses of Outer Space.

that aim to be beneficial to everyday life. Nevertheless, every single of thousands of planned satellites could become the space bullet, and even without the ability to manoeuvre, they possess a considerable challenge to space security and space traffic management. Follows, satellites may serve as platforms for space weapons. For example, the U.S. claims they could deploy space-based missile defence [67]. In such a case, without further legal consideration, a substantial number of satellites would be able to shoot on both Earth and space assets. Besides, since the satellites may serve many purposes, satellites could be secondarily designed to bear a space weapon. Next, cyberspace can be exploited for harmful activity with destructive potential. The cyber resilience of space assets is underestimated, and satellites are not sufficiently cyber-protected and can be overtaken by enemy actors. Last but not least, active debris removal systems that will be vital to maintain open access to outer space can remove both orbital debris as well as functional systems and are thus efficient space weapons. Overall, all the discussed technology has destructive potential and may eventually become part of a comprehensive counterspace strategy.

However, the impact of dual-use weaponization may be multiplied by combination with space hybrid operations and may become an element of space warfare strategy. As was demonstrated, the outer space has its features setting the rules for war and consists of strategic routes or lines of communication that may be contested by spacefaring nations to reach control over the Earth. The states are already developing advanced kinetic physical, non-kinetic physical, electronic, and cyber counterspace capabilities that aim to *"deceive, disrupt, deny, degrade, or destroy space systems."* [26]

On the other hand, it is vital to point out the space conflict would have a severe impact on the space environment. Up to date, over 23 000 on-orbit objects are recognized by U.S. Space Surveillance Network (SSN), from which only a small fraction are operational satellites. SSN tracks objects between 5 and 10 cm in low Earth orbit and 30 cm to 1 m in geosynchronous orbit. Overall, it was estimated about 500 000 orbital debris larger than 1 cm is orbiting around the Earth. Majority of the debris is located in LEO, the most occupied orbit where they exceed high velocities and possess a danger to other systems [72]. Especially the direct-ascend kinetic ASAT weapons are a threat to the proliferation of orbital debris. On January 2007, China shot down their satellite Fengyun-1C (FY–1C) with a modified two-stage ballistic missile DF-21 with a payload of 600 km at an altitude of 863 km. Though the risk of space debris was well-known, the Chinese ASAT test generated the largest debris cloud ever made, counting over 3000 trackable objects by Space Surveillance Network. After the test, 97% of debris remained orbiting at an altitude between 175 km and 3600 km. Until 2017, only 6% of debris decayed, an estimated 79% of debris will be still orbiting in 2108 possesses a threat to a substantial number of other space systems [73]. Discussed dual-use technology in many cases share ASAT features and its abuse for offensive purposes would likely result in the proliferation of new space debris. The space conflict would thus have significantly affected both state and non-state actors, increasing the risk of collisions and causing troubles to space traffic management. However, in theory, some of the proposed techniques can mitigate the risk of intended proliferation of orbital debris and, for instance, efficient cyber operation supported by advanced ADR and RPOs methods could potentially disrupt adversary's satellite architecture with minimal danger to allied systems.

Last but not least, it must be noted that the implications of dual-use technologies have a much broader scope than as outlined in the article. For instance, deflection methods for the planetary defence against the asteroids and comets in many cases resemble with the mentioned hazardous features. Planetary defence kinetic impactor would, in essence, consists of the delivery vehicle and kinetic payload – the same as the kinetic ASAT weapons. The same is valid for the nuclear explosion that must incorporate the delivery vehicle and nuclear payload that would be sent towards the incoming threat. It should be noted that both kinetic and nuclear technology have a convincing level of readiness and could be deployed with relatively short notice [74]. Thus, albeit the nuclear tests in outer space were already forbidden by the Partial Test Ban Treaty in 1963, they may represent a viable source of planetary defence technology [75]. Exceptionally dubious is also space application of laser technology. The recently discussed topic is the construction of 100-GW lasers that could serve as propulsion of interstellar travels [76], however, lasers have a broad spectrum of utilization ranging from planetary defence to active debris removal and space weapons.

6. Conclusion

Outer space is an indispensable strategic domain that must encounter new challenges resulting from the emergence of new technology. The realist paradigm persists in the behaviour of major space powers and the absence of space norms forges the opportunities for space weaponization. The intent of beneficial or malicious utilization of space technology is unclear due to its dual-use nature with potentially destructive implications. The article illustrated that demonstrated space-related technology, namely space launch vehicles, small satellites, satellites as weapon platforms, information technology and active debris removal systems, have broad dual-use consequences that can eventually lead to the weaponization of outer space. Space law does not satisfactorily address the definition of space weapon and omits comprehensive restrictions on their further development. The proliferation of weapon-related technology remains unsolved, especially in regard to malicious utilization of dual-use technology that could be integrated into the space warfare strategy. However, unpremeditated inception of space conflict would most likely result in an undesired proliferation of space debris with irreversible impact on the space environment. The states should promote responsible behaviour concerning emerging space technology as was proposed, for instance, by the European Union Code of Conduct for Outer Space Activities and should seek further consideration of space norms that would sustain peaceful uses of outer space. Finally, the implications of the article open ground for further research that would ensure the peaceful uses of outer space, contribute to the establishment of the new space norms and promote responsible behaviour of space actors.

Funding

This article was supported by the grant SVV – 260 595 (Political Order in a Time of Change)

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] R. Harrison, Unpacking the three C's: congested, competitive, and contested space, Astropolitics 11 (3) (2013) 123–131, https://doi.org/10.1080/14777622.2013.838820.
[2] J. Johnson-Freese, A new US-Sino space relationship: moving toward cooperation, Astropolitics 4 (2) (2006) 131–158, https://doi.org/10.1080/14777620600910571.
[3] J. Johnson-Freese, Space Warfare in the 21st Century: Arming the Heavens, Routledge, New York, 2017.
[4] Foreign Ministers Take Decisions to Adapt NATO, Recognize Space as an Operational Domain, North Atlantic Treaty Organization, 2019. https://www.nato.int/cps/en/natohq/news_171028.htm. (Accessed 28 March 2020).
[5] H. Kleinberg, On war in space, Astropolitics 5 (1) (2007) 1–27, https://doi.org/10.1080/14777620701544600.
[6] E. Dolman, Geostrategy in the space age: an astropolitical analysis, J. Strat. Stud. 22 (2–3) (1999) 83–106, https://doi.org/10.1080/01402399908437755.
[7] E. Dolman, Astropolitik: Classical Geopolitics in the Space Age, Frank Cass Publishers, London, 2002.
[8] SATELLITES' GAZE PROVIDES NEW LOOK AT WAR, The Washington Post, 1991. https://www.washingtonpost.com/archive/politics/1991/02/19/satellites-gaze-

provides-new-look-at-war/768b19e4-a1da-4f40-8267-28a5dda48726/. (Accessed 15 September 2019).
[9] B.E. Bowen, War in Space: Strategy, Spacepower, Geopolitics, Edinburgh University Press, Edinburg, 2020.
[10] B. Doboš, J. Pražák, To clear or to eliminate? Active debris removal systems as antisatellite weapons, Space Pol. 47 (2019) 217–223, https://doi.org/10.1016/j.spacepol.2019.01.007.
[11] T. Harrison, K. Johnson, T. Roberts, R. Kehler, Space threat assessment, CSIS (2018). Available at, 2018, https://aerospace.csis.org/wp-content/uploads/2018/04/Harrison_SpaceThreatAssessment_FULL_WEB.pdf. (Accessed 18 November 2018).
[12] B. Weeden, V. Samson, Op-ed | India's ASAT test is wake-up call for norms of behavior in space, Spacenews.com, https://spacenews.com/op-ed-indias-asat-test-is-wake-up-call-for-norms-of-behavior-in-space/, 2019. (Accessed 30 December 2019).
[13] J. Garamore, Trump signs law establishing U.S. Space force, U.S. Department of Defense, https://www.defense.gov/Explore/News/Article/Article/2046035/trump-signs-law-establishing-us-space-force/(accessed 13 June, 2020).
[14] S. Erwin, Five things to know about U.S. Space Command, SpaceNews.com (2019). Available at: https://spacenews.com/five-things-to-know-about-u-s-space-command/. (Accessed 20 November 2019).
[15] S. Erwin, Air Force: SSA Is No More; It's 'Space Domain Awareness', SpaceNews.com, 2019. Available at, https://spacenews.com/air-force-ssa-is-no-more-its-space-domain-awareness/?fbclid=IwAR3tKAbPa9CauVvoKLYxDzaaOAZD64TTn5b1JCqFhB-V7SNefo4nrkKSKgQ. (Accessed 20 November 2019).
[16] B. Chow, H. Sokolski, The United States Should Follow France's Lead in Space, SpaceNews.Com, 2019. https://spacenews.com/the-united-states-should-follow-frances-lead-in-space/. (Accessed 29 March 2020).
[17] H. Weitering, France Is Launching a 'Space Force' with Weaponized Satellites, Space.com, 2019. https://www.space.com/france-military-space-force.html. (Accessed 18 September 2019).
[18] M. Peel, C. Shepherd, A. Williams, Vulnerable Satellites: the Emerging Arms Race in Space, Financial Times, 2019. Available at: https://www.ft.com/content/a4300b42-f3fe-11e9-a79c-bc9acae3b654?sharetype=blocked&fbclid=IwAR3RAXRzsz8VOD118Sq4irsr-nHI8peoGTJRG_EN7r79bDP2Gys5Dns6sxA. (Accessed 20 November 2019).
[19] J. Johnson-Freese, Space as a Strategic Asset, Columbia Univ. Press, New York, 2007.
[20] P. Larsen, Issues relating to civilian and military dual uses of GNSS, Space Pol. 17 (2) (2001) 111–119, https://doi.org/10.1016/S0265-9646(01)00007-8.
[21] K. Hebert, Regulation of space weapons: ensuring stability and continued use of outer space, Astropolitics 12 (1) (2014) 1–26, https://doi.org/10.1080/14777622.2014.890487.
[22] T. Hitchens, M. Katz-Hyman, J. Lewis, U.S. SPACE WEAPONS, Nonproliferation Rev. 13 (1) (2006) 35–56, https://doi.org/10.1080/10736700600861350.
[23] M. Krepon, M. Katz-Hyman, Space weapons and proliferation, Nonproliferation Rev. 12 (2) (2005) 323–341, https://doi.org/10.1080/10736700500378950.
[24] Treaty on the prevention of the placement of weapons in outer space, the Threat or Use of Force against Outer Space Objects(Draft), Ministry of Foreign Affairs of the People's Republic of China (2014). Available at: https://www.fmprc.gov.cn/mfa_eng/wjb_663304/zzjg_663340/jks_665232/kjfywj_665252/t1165762.shtml. (Accessed 6 May 2019).
[25] J. Robinson, M. Šmuclerová, L. Degl'Innocenti, L. Perrichon, J. Pražák, EUROPE'S preparedness to respond to space hybrid operations, PSSI (2018). Available at: https://www.pssi.cz/download//docs/8252_597-europe-s-preparedness-to-respond-to-space-hybrid-operations.pdf. (Accessed 2 November 2020).
[26] B. Weeden, V. Samson, Global Counterspace Capabilities: an Open Source Assessment. Secure World Foundation, 2018, pp. 1–148. Available at: https://swfound.org/media/206118/swf_global_counterspace_april2018.pdf. (Accessed 15 January 2019).
[27] F. Von der Dunk, A European "equivalent" to United States export controls: European law on the control of international trade in dual-use space technologies, Astropolitics 7 (2) (2009) 101–134, https://doi.org/10.1080/14777620903094826.
[28] D. Mistry, B. Gopalaswamy, Ballistic missiles and space launch vehicles in regional powers, Astropolitics 10 (2) (2012) 126–151, https://doi.org/10.1080/14777622.2012.696014.
[29] Hague Code of conduct against ballistic missile proliferation (HCOC), Nti.org (2019). Available at: https://www.nti.org/learn/treaties-and-regimes/hague-code-conduct-against-ballistic-missile-proliferation-hcoc/. (Accessed 8 March 2019).
[30] International Code of conduct against ballistic missile proliferation, United Nations General Assembly (2003). Available at: https://www.nonproliferation.eu/hcoc/wp-hcoc/uploads/2015/07/Hague-Code-of-Conduct-A-57-724-English.pdf. (Accessed 8 March 2019).
[31] V. Mahajan, Chinese anti-satellite means: criticality and vulnerability of Indian satellites, CLAWS Journal (2016) 172–188. Available at: https://archive.claws.in/images/journals_doc/1088405263_VaydeeshMahajan.pdf. (Accessed 30 December 2019).
[32] J. Trevithick, SpaceX Exec Says Company Would Launch A Weapon into Space in, Defense Of This Country, 2018. The Drive. Available at: http://www.thedrive.com/the-war-zone/23733/spacex-exec-says-company-would-launch-a-weapon-into-space-in-defense-of-this-country. (Accessed 8 March 2019).
[33] S. Erwin, SpaceX President Gwynne Shotwell: 'We Would Launch a Weapon to Defend the U.S, SpaceNews.com, 2018. Available at: https://spacenews.com/spacex-president-gwynne-shotwell-we-would-launch-a-weapon-to-defend-the-u-s/. (Accessed 8 March 2019).
[34] J. McCurry, D. Gayle, North Korea rocket launch: UN security council condemns latest violation, Guardian (2016). Available at: https://www.theguardian.com/world/2016/feb/07/north-korea-launches-long-range-rocket-it-claims-is-carrying-a-satellite. (Accessed 8 March 2019).
[35] J. Straub, Towards operating standards for cube satellites and small spacecraft, Astropolitics 15 (1) (2017) 77–95, https://doi.org/10.1080/14777622.2017.1289048.
[36] G. Konecny, SMALL SATELLITES – A TOOL FOR EARTH OBSERVATION? University of Hannover, Hannover, 2004. Available at: https://www.researchgate.net/publication/229028414_Small_satellites-A_tool_for_Earth_observation. (Accessed 8 March 2019).
[37] D. Paikowsky, What Is new space? the changing ecosystem of global space activity, New Space 5 (2) (2017) 84–88, https://doi.org/10.1089/space.2016.0027.
[38] E. Quintana, The new space age: questions for defence and security, Rusi 162 (3) (2017) 88–109, https://doi.org/10.1080/03071847.2017.1352377.
[39] UCS satellite database, union of concerned scientist, Available at: https://www.ucsusa.org/resources/satellite-database, 2020. (Accessed 25 October 2020).
[40] M. Harris, SpaceX plans to put more than 40,000 satellites in space, New Scientist, Available at: https://www.newscientist.com/article/2220346-spacex-plans-to-put-more-than-40000-satellites-in-space/, 2019. (Accessed 25 October 2020).
[41] The community research and development information service, A modular propulsion system for small satellites, Cordis.europa.eu (2020). Available a, https://cordis.europa.eu/article/id/413500-a-modular-propulsion-system-for-small-satellites. (Accessed 23 March 2020).
[42] G.S. Sachdeva, Space Mines: Dialectics of Legality, Astropolitics 7 (3) (2009) 135–149, https://doi.org/10.1080/14777620903073887.
[43] J. Sciutto, J, Rizzo, War in space: kamikazes, kidnapper satellites, lasers. CNN, Available at: https://edition.cnn.com/2016/11/29/politics/space-war-lasers-satellites-russia-china/index.html, 2016. (Accessed 21 August 2018).
[44] B. Weeden, Dancing in the dark redux: recent Russian rendezvous and proximity operations in space (page 1), Thespacereview.com (2015). Available at: http://www.thespacereview.com/article/2839/1. (Accessed 9 March 2019).
[45] J. Sheldon, Russia attempts to shift blame to United States over satellite inspection allegations, SpaceWatch.Global. (2020). Available at: https://spacewatch.global/2020/02/russia-attempts-to-shift-blame-to-united-states-over-satellite-inspection-allegations/. (Accessed 30 March 2020).
[46] B. Chow, Stalkers in Space: Defeating the Threat, Strategic Studies Quarterly, 2017, pp. 82–116. Available at: https://www.airuniversity.af.edu/Portals/10/SSQ/documents/Volume-11_Issue-2/Chow.pdf. (Accessed 9 March 2019).
[47] R. Barbosa, China "secretly" launch three satellites via Long March 4C, Nasaspaceflight.com (2013). Available at: https://www.nasaspaceflight.com/2013/07/china-secretly-long-march-4c-three-sats/. (Accessed 9 March 2019).
[48] C. Clark, China satellite SJ-17, friendly wanderer? Breaking Defense (2018). Available at: https://breakingdefense.com/2018/04/china-satellite-sj-17-friendly-wanderer/. (Accessed 8 March 2019).
[49] B. Weeden, Dancing in the Dark: the Orbital Rendezvous of SJ-12 and SJ-06F (Page 1), Thespacereview.com, 2010. Available at: http://www.thespacereview.com/article/1689/1. (Accessed 9 March 2019).
[50] C. Clark, New spy satellites revealed by air force; will watch other sats, breaking Defense, Available at: https://breakingdefense.com/2014/02/new-spy-satellites-revealed-by-air-force-will-watch-other-sats/, 2014. (Accessed 9 March 2019).
[51] B. Weeden, X-37B Orbital Test Vehicle Fact Sheet, Secure World Foundation, 2017, pp. 1–4. Available at: https://swfound.org/media/205879/swf_x-37b_otv_fact_sheet.pdf. (Accessed 9 March 2019).
[52] XSS-11 Micro Satellite, The Air For Research Laboratory, vols. 1–2. Available at: https://www.kirtland.af.mil/Portals/52/documents/AFD-111103-035.pdf?ver=2016-06-28-110256-797, 2011 (accessed 9 March 2019).
[53] 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.
[54] Strategic Defense Initiative (SDI), Atomic heritage foundation, Available at: https://www.atomicheritage.org/history/strategic-defense-initiative-sdi, 2018. (Accessed 9 March 2019).
[55] W. Spacy II, Assessing the military utility of space-based weapons, Astropolitics 1 (3) (2003) 1–43, https://doi.org/10.1080/14777620312331269989.
[56] Missile Defense Review, United States Department of Defense, 2019. Available at: https://assets.documentcloud.org/documents/5687662/2019-MISSILE-DEFENSE-REVIEW.pdf. (Accessed 9 March 2019).
[57] S. Freedberg, Space-Based Missile Defense Can Be Done: DoD R&D Chief Griffin, Breaking Defense, 2018. Available at: https://breakingdefense.com/2018/08/space-based-missile-defense-is-doable-dod-rd-chief-griffin/. (Accessed 10 March 2019).
[58] M. Selinger, DoD's Griffin eyes using directed energy for space-based missile Defense, Defense Dail. (2018). Available at: https://www.defensedaily.com/dods-griffin-eyes-using-directed-energy-space-based-missile-defense/pentagon/. (Accessed 10 March 2019).
[59] P. McLeary, White house missile Defense review: space lasers, weapons on table, breaking Defense, Available at: https://breakingdefense.com/2019/01/white-house-missile-defense-review-space-lasers-weapons-on-table/, 2019. (Accessed 10 March 2019).
[60] D. Fidler, Cybersecurity and the New Era of Space Activities, Council on Foreign Relations, 2018. Available at: https://www.cfr.org/report/cybersecurity-and-new-era-space-activities. (Accessed 20 November 2019).
[61] S. Ducaru, NATO Advances in its New Operational Domain: Cyberspace, Fifth Domain, 2018. Available at: https://www.fifthdomain.com/opinion/2018/07/05/nato-advances-in-its-new-operational-domain-cyberspace/. (Accessed 14 January 2019).

[62] Cyber Strategy Summary, US Department of Defense, 2018, pp. 1–7. Available at: https://media.defense.gov/2018/Sep/18/2002041658/-1/-1/1/CYBER_STRATEGY_SUMMARY_FINAL.PDF. (Accessed 14 January 2019).
[63] J. Robinson, J. Pražák, L. Perrichon, Europe's management of space hybrid threats, in: 69th International Astronautical Congress, IAC), 2018.
[64] RemoveDEBRIS Completes Reconnaissance and Navigation Test, Surrey.ac.uk, 2018. Available at: https://www.surrey.ac.uk/news/removedebris-completes-reconnaissance-and-navigation-test. (Accessed 15 March 2019).
[65] Net successfully snares space debris, Surrey.ac.uk (2018). Available at: https://www.surrey.ac.uk/news/net-successfully-snares-space-debris. (Accessed 15 March 2019).
[66] Harpoon successfully captures space debris, Surrey.ac.uk (2019). Available at: https://www.surrey.ac.uk/news/harpoon-successfully-captures-space-debris. (Accessed 15 March 2019).
[67] United Nations Treaties and Principles on Outer Space, United Nations, New York, 2018. Available at: https://www.unoosa.org/pdf/publications/st_space_11rev2E.pdf.
[68] W. Von Kries, The demise of the ABM Treaty and the militarization of outer space, Space Pol. 18 (3) (2002) 175–178, https://doi.org/10.1016/S0265-9646(02)00016-4.
[69] J. Foust, U.S. Dismisses, Space Weapons Treaty Proposal as "Fundamentally Flawed", SpaceNews.com, 2014. Available at: https://spacenews.com/41842us-dismisses-space-weapons-treaty-proposal-as-fundamentally-flawed. (Accessed 23 March 2019).
[70] Z. Shabbir, A. Sarosh, Counterspace operations and nascent space powers, Astropolitics 16 (2) (2018) 1–22, https://doi.org/10.1080/14777622.2018.1486792.
[71] M. Listner, R. Rajagopalan, The 2014 PPWT: a new draft but with the same and different problems, Thespacereview.com (2014). Available at: http://www.thespacereview.com/article/2575/1. (Accessed 23 March 2019).
[72] R. Liemer, C. Chyba, A verifiable limited test ban for anti-satellite weapons, Wash. Q. 33 (3) (2010) 149–163, https://doi.org/10.1080/0163660X.2010.492346.
[73] B. Weeden, Chinese Anti-satellite Test Fact Sheet, Available at:, Secure World Foundation, 2007, pp. 1–3, 2007, https://swfound.org/media/9550/chinese_asat_fact_sheet_updated_2012.pdf. (Accessed 25 December 2018).
[74] B. Wie, Hypervelocity nuclear interceptors for asteroid disruption, Acta Astronaut. 90 (1) (2013) 146–155, https://doi.org/10.1016/j.actaastro.2012.04.028.
[75] B. Doboš, J. Pražák, M. Němečková, Atomic salvation: a case for nuclear planetary defence, Astropolitics 18 (1) (2020) 73–91, https://doi.org/10.1080/14777622.2020.1719003.
[76] Češi chtějí pomoci s projektem Stephena Hawkinga, Cílem je poprvé dostat sondu do jiné planetární soustavy, Hospodářské noviny, Available at: https://archiv.ihned.cz/c7-66646500-r49c8-5c60987c7d7b363?fbclid=IwAR157w8AytIEwrdSjoi_xTWiDHhLfa00goM0FamnGsC-eUpFzsLmphNqkw0, 2019. (Accessed 30 September 2019).
[77] B. Weeden, Chinese Direct Ascent Satellite Testing, Secure World Foundation, 2020. Available at: https://swfound.org/media/207050/swf_chinese_da-asat_aug2020.pdf. (Accessed 24 October 2020).
[78] Military and security developments involving the people's Republic of China, 2020. Available at: https://media.defense.gov/2020/Sep/01/2002488689/-1/-1/1/2020-DOD-CHINA-MILITARY-POWER-REPORT-FINAL.PDF, 2020 (accessed 24 October 2020).
[79] D.A. Barnhart, R. Rughani, On-orbit servicing ontology applied to recommended standards for satellites in earth orbit, Journal of Space Safety Engineering 7 (2020) 83–98, https://doi.org/10.1016/j.jsse.2020.02.002.
[80] M. Manulis, C.P. Bridges, R. Harrison, et al., Cyber security in new space, Int. J. Inf. Secur. (2020), https://doi.org/10.1007/s10207-020-00503-w.
[81] R. Synovitz, Is Iran using space launches to develop long-range missiles?, RFE/RL, Available at: https://www.rferl.org/a/is-iran-converting-space-launchers-into-long-range-missiles-/30437113.html, 2020. (Accessed 25 October 2020).
[82] 107,000 planned satellites by 2029, Youtube, Available at: https://www.youtube.com/watch?v=oWB7ZySDHg8 , 2020 (accessed 25 October 2020).
[83] T.M. Blatt, Aegis ashore deployment jeopardizes stability in east asia, Harv. Int. Rev. (2019). Available at: https://hir.harvard.edu/aegis-ashore-deployment-jeopardizes/. (Accessed 25 October 2020).
[84] About Astroscale, Astroscale, Available at: https://astroscale.com/about-astroscale/about/, 2020. (Accessed 26 October 2020).
[85] Clearspace One – A Mission to Make Space Sustainable, Clearspace Today, 2020. Available at: https://clearspace.today/. (Accessed 26 October 2020).
[86] What is the MILAMOS project? McGill University (2020). Available at: https://www.mcgill.ca/milamos/. (Accessed 26 October 2020).
[87] The Woomera Manual, The University of Adelaide, 2020. Available at: https://law.adelaide.edu.au/woomera/. (Accessed 26 October 2020).

Jakub Pražák is a PhD candidate of International Relations at the Charles University in Prague. He holds a bachelor's degree in Political Science and International Relations and two master's degrees in Security Studies and International Relations. His dissertation thesis focuses on the "Emerging Threats to Space Security and Protection of Space Assets" that is conducting in collaboration with the Prague Security Studies Institute where he is also contributing to the research within the Space Security Program.