IV.3

MILITARY AND DEFENCE ISSUES IN SPACE

CHAPTER 10

CHALLENGES OF PRACTICAL SPACE OPERATIONS UNDER THE OUTER SPACE TREATY: OPERATIONS IN A LEGAL REGIME OF A DIFFERENT ERA

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Abstract

Outer space is of the utmost importance for our society. It is endless, but still limited. It is used to support activities related to business, state, and defence, and while it is replaceable, this replacement would negatively affect our way of life. Its importance also creates a vulnerability that can be exploited by adversaries, however, pure chance can trigger events that can lead to catastrophes. Outer space is, by its very nature, an international environment. Still, the international legal regime regulating it is surprisingly limited compared to its vital importance. This chapter presents several examples wherein the regulations have fallen behind the advance of technology and operations. These shortcomings did not come to light until now only because of practical technology's inability to realise what is theoretically possible, professionalism of the operators, and sheer luck. It would be unwise to count on these reasons in the future. This chapter organises the examples into the following groups: delimitation of airspace and outer space and operations in the border region; sovereignty and zoning of outer space related to spacecraft; operations of active spacecraft and removal of inactive ones; and defence-related technology development. At the end of each section, questions and suggestions are presented for the legal community to examine and discuss. It is my desire to use this opportunity to support the legislative effort necessary to develop legally binding and enforceable rules and

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regulations, so as to enable the sustainable long-term use of outer space – a natural resource incomparable to any other.

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1. Introduction

Outer space is a special realm, both physically and legally. Most of our understanding about the earth's environment – just like our earthly laws and rules of behaviour – can be applied to space only with extreme caution. The legal regime of outer space was established decades ago, when the utilisation of outer space was very different. At that time, the actors executing space activities were state agencies, including military forces and national security organisations. Commercial space activities were envisioned, but were understood as state controlled. Most of the space operations were related to exploration and support of state functions, including the provisioning of public services and the support of security and military operations. The small number of spacefaring nations and the limited scope of activities suggested that a limited set of rules would be enough, since these were based on a common understanding and mutual cooperation.

It soon became apparent that this would not be the case. Two significant examples can be recalled (among many more) to illustrate the fragility of the space treaties, even at that time. The first example is the case of the Soviet spacecraft Kosmos[1] 482. Kosmos 482 was launched on 31 March 1972 from Baikonur Cosmodrome, on a launch vehicle generally used to launch the Venera series space probes, onto a trajectory typical as a parking orbit for interplanetary missions.[2] However, the upper stage suffered a malfunction, and the space vehicle separated into multiple pieces. At least one object (international designation 1972-023E, most likely the Venus descent module) is still in orbit. One object reentered just a day after launch (1972-023B, launch vehicle second stage), another (1972-023A, main spacecraft module) reentered in 1981, and a further one (1972-023D, launch vehicle third stage) reentered in 1983 without any incident. However, object 1972-023C, an intermediate stabilising platform used for interplanetary launches onboard Molniya launch vehicles, re-entered on 2 April 1972.[3] During reentry, the object disintegrated, and

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[1] The name "Kosmos" was used by the Soviet Union, and is still used by Russia, to designate classified, unspecified, or failed space missions. Usually, Kosmos spacecraft were announced with cover stories of unspecified, but usually technological or scientific, research missions.

[2] Langbroek, 2022.

[3] Zak, 2011.

four spherical tanks made of titanium reached the surface in New Zealand, causing negligible property damage.

The tanks were marked with Russian markings and were identified as objects from the Kosmos 482 launch; therefore, the New Zealand government contacted the Soviet Union to return the debris. However, the Soviet Union denied ownership, and the case came to a dead end.

The second example of the fragility of the space legal regime is the case of the Bogotá Declaration.[4] The Bogotá Declaration was issued by eight countries located along the equator, which asserted their sovereignty over sections of the geostationary orbit[5] while leaving other volumes of outer space as the common heritage of mankind, as described in the Outer Space Treaty.

The argument behind the assertation was that the geostationary orbit is a consequence of the gravity and rotation of the Earth; therefore, this orbit is not simply a location in outer space but rather a natural resource directly linked to the territory of the country at the subsatellite point.

The Bogotá Declaration reiterated the missing definition of outer space in the Outer Space Treaty of 1967.[6] It referenced Resolutions 2692[7] and 3281[8] of the United Nations (UN) General Assembly.[9] Altogether, the declaration presented an argument stating that since geostationary orbit is possible because of Earth's gravity, and Earth's gravity is a consequence of Earth's mass, the sovereignty over a given Earth's mass is granted by the UN resolutions, and outer space is not defined internationally; therefore, sovereignty over sections of the geostationary orbit can be established.

Ultimately, the Bogotá Declaration failed to gain any significant international support outside the eight nations. However, loopholes exploited by the declaration still have not been closed by international laws.

The advancement of technology and proliferation of space activities created and, in my opinion, continue to create many similar problematic cases. In this chapter, I plan to outline a selection of these cases and call for the legal community to create universally accepted legal controls to enable safe and effective space operations, as well as prevent any possible conflicts (including legal and physical).

This chapter will present cases according to the following structure:

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[4] Durrani, 2017.

[5] The geostationary orbit is a subset of the geosynchronous orbits around the Earth. The time an object on a geosynchronous orbit requires to orbit the Earth precisely equals the time the Earth needs to complete one rotation. When the orbital plane coincides with the equatorial plane, the object orbits without any relative motion in reference to an observer located on the surface of the Earth (no East-West and no North-South relative motion).

[6] UN General Assembly, 1967.

[7] UN General Assembly, 1970.

[8] UN General Assembly, 1974.

[9] These resolutions confirmed the sovereignty of states over their natural resources.

An important question regarding the legal status of space operations is the delimitation of the atmosphere (where state sovereignty is in effect) and outer space (where sovereignty is out of the question). Section 2 examines cases where the lack of uniform and internationally accepted delimitation between the atmosphere and outer space hinders the development or execution of space activities. Selected examples for this section include the following:

- Hypersonic flights in the mesosphere
- Suborbital spaceflight
- Flights where different sections use different principles of flight – alternating between Keplerian or suborbital trajectories and atmospheric aerodynamic (hypersonic) flight

There is also a question of sovereignty in outer space. According to the existing legal regime, state sovereignty ends at the outer extremes of a spacecraft body, but safe and effective space operations require separation of spacecraft in orbit. Section 3 presents arguments why there needs to be a volume around each spacecraft that effectively belongs to said spacecraft because of the uncertainties of the tracking and manoeuvring systems. Selected examples for this section include the following:

- Legality and enforceability of the existing keepout zones used voluntarily in international space activities (International Space Station [ISS] operations and the Artemis Accords)
- Legal status of non-cooperative rendezvous and proximity operations (close approach and formation flying by a spacecraft with another spacecraft)
- Legality of the enforcement of unilaterally declared security zones (patrol spacecraft)

Next, in Section 4, I discuss the definition of operational spacecraft as well as responsibilities of spacecraft operators during and after the useful operational life of a spacecraft (closely related to damages). Selected examples for this section include the following:

- Lack of definition of an operational spacecraft and the valuation of an inoperational spacecraft
- Orbital debris removal by third parties or as a public service
- Chain-event effects and indirect damages

Next, in Section 5, I discuss the regulation of legal self-defence technologies with offensive applications, dual-use technologies, and weaponisable commercial space technologies. Selected examples for this section include the following:

- Orbital debris removal (weaponisable as a co-orbital counterspace weapon)
- Ballistic missile defence (legal self-defence capability that can be used as a direct-ascent counterspace weapon)
- Directed energy jammers

2. Questions Arising from the Lack of Delimitation of Airspace and Outer Space

There is no internationally accepted general definition of outer space, spacecraft, space activity, or the boundary between the sovereign airspace and outer space. Sovereign states have their defined responsibilities in their airspace (e.g. see Chapter 1 of the Convention on International Civil Aviation). Simultaneously, because of the Outer Space Treaty, there is no sovereignty in outer space. There needs to be a line where these rules and the associated responsibilities change based on different situations.

While there are no defined rules for delimitation, there exist dozens of theories for it. These can be grouped into two main categories: spatial delimitation and functional delimitation theories. However, neither of these can provide a universal answer.[10]

Spatial delimitation theories arbitrarily select either an altitude or a physical phenomenon to calculate an altitude, the volume below which is part of the airspace and above which is part of outer space. The limit most often mentioned is the Kármán line (as an arbitrarily selected physical phenomenon); however, the actual altitude (100 km above main sea level) does not correspond to the Kármán line[11] and so is also an arbitrarily selected altitude.

Functionalist delimitation theories focus on the activity itself and not its physical location. Practically, functionalist delimitation theories can be summarized as stating that an object that does space activities is in outer space. However, since space activities are not defined in international law, this approach again calls for arbitrarily selected activities based on the definition. For example, if the arbitrarily selected criterion is completing an orbit around Earth, an experimental, very low Earth orbit[12] satellite that orbits (for a very limited time) on a 180-km circular orbit can be defined as a spacecraft and therefore as being in outer space; however, the target vehicle of an antiballistic missile test that reaches an altitude of several thousand kilometres on a suborbital trajectory does not fall under this definition.

This lack of internationally accepted legal definition makes it difficult to even write about the problem itself – How to differentiate between spaceflight and atmospheric

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[10] Bartóki-Gönczy and Sipos, 2022.

[11] The Kármán line is based on the fact that the diminishing atmosphere can only provide enough lift for aerodynamic flight if the airspeed is increasing. When the required airspeed reaches the first orbital speed, the need for lift disappears, since from here on the object is not flying aerodynamically but is on a Keplerian orbit. The Kármán line is not constant but can be calculated to lie around 85–90 km, depending on the density of the upper atmosphere. The problem with this theory is that there are practical atmospheric effects (drag and chemical interactions) above this altitude, while sustained orbital operations are not possible here. For a detailed analysis of the Kármán line, see: McDowell, 2018.

[12] Laursen, 2023.

flight if we do not know where space is and what is spaceflight? Therefore, this chapter also uses the expression “exoatmospheric flight” to describe flights where physical effects other than aerostatics or aerodynamics dominate flight dynamics.

2.1. Hypersonic Mesospheric Flight

The mesosphere is the layer of the Earth’s atmosphere lying above the stratopause and below the mesopause, roughly between 50 km and 80–90 km (varying, depending on the geographical location and upper atmospheric weather). The most important property of the mesosphere (and which is used to define it) is that the temperature decreases with altitude.[13]

The mesosphere cannot be reached with conventional aerodynamic aircrafts and is practically unreachable for aerostatic balloons (although it is not impossible for special balloons made of ultralight materials to reach it). Sustained (straight and level) aerodynamic flight is only possible at hypersonic velocities.

Hypersonic flight is usually defined as supersonic flight above Mach 5.[14] Practically, however, hypersonic flight is usually associated with rocket- or scramjet-[15]powered aerodynamic vehicles (capable of sustained straight and level flight) and hypersonic gliders that convert their potential energy to kinetic energy to achieve limited manoeuvring and flight time. Hypersonic gliders are usually launched with rocket power, including military ballistic missiles (hypersonic warheads such as the Russian Avangard[16] or the discontinued US AMaRV[17]), modified space launchers (RocketLab Electron HASTE[18]), and suborbital launch vehicles.

One significant physical phenomenon associated with hypersonic flight is the heat transfer between the vehicle and the surrounding air. This limits the practical hypersonic flight to altitudes where the air density is relatively low (to reduce heating) but still sufficient to generate lift. This practically coincides with the mesosphere.

As of today, there are very limited commercial activities, and somewhat more research activities, related to hypersonic flights. Nevertheless, there are military applications of this flight regime, mostly involving weapons delivery and missile defence. The commercial applications are expected to be developed with the advancement of technology, mostly in transportation.

The mesosphere and hypersonic flights are in a grey zone. The physical domain is inside the atmosphere, and the flight is based on the interaction with the air. However, this domain is unreachable for most of the air defence systems used by

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[13] For a short description of the mesosphere, see: University of Wuppertal, no date.

[14] Brockmann and Schiller, 2022.

[15] Scramjet is short for supersonic combustion ramjet, an air-breathing thermal engine without moving parts in which the combustion that generates the thrust occurs in a supersonic airflow environment. For a short description of scramjets, see: SKYbrary, no date.

[16] Missilethreat, 2021.

[17] Bunn, 1984.

[18] Rocketlab, no date.

militaries, and it is even above the detection threshold of most unmodified air surveillance radars. Therefore, practical enforcement of state sovereignty is questionable. This is an important point, since the basis of sovereignty over the seas originally arose from the ability of a coastal nation to defend its shores with military power (coastal defence artillery).[19]

The technology used to reach the mesosphere and perform flight operations there is closely related to space technology. Thermal protection of the vehicle needs to be comparable to the thermal protection used in spacecraft reentry, as the speeds and altitudes are also comparable. Scramjet propulsion is exclusively an aerial system, but rocket propulsion used in hypersonics is again directly comparable to space technology. Moreover, a rocket-powered hypersonic vehicle is capable of flight only slightly above the most often cited boundary of airspace and outer space, with its operational radius limited only by its onboard fuel. Therefore it is theoretically possible to complete a circumnavigation of Earth at an altitude of, for example, 110 km, with a hypersonic lift vehicle (which in this case might fall under the definition of spacecraft by either the functionalist or spatial delimitation); at the same time, a similar vehicle can complete the circumnavigation with exactly the same technology and operational rules at 90 km, or just execute an intercontinental transfer at these altitudes (or even lower). It must be noted that such circumnavigation is possible at velocities lower than the corresponding orbital velocity, using any aerodynamic lift still present, but mostly engine thrust to counteract gravity.

Third, a hypersonic glider can start its flight as a suborbital or even orbital spacecraft. Since a hypersonic glide is a manoeuvre converting potential energy to kinetic energy, the vehicle needs to reach a certain altitude and then start falling back towards the Earth (executing a reentry from space or simply starting an unpowered, almost horizontal flight in the atmosphere). During the glide, the vehicle uses its aerodynamic surfaces to generate lift and steering forces; meanwhile, the associated drag slows it down. To avoid losing its kinetic energy, the vehicle must lower its altitude. Ultimately, the combined energy will be reduced below a certain level where the hypersonic flight is finished (because the vehicle either slows down or hits the surface). This set of manoeuvres is comparable to a controlled reentry from outer space; however, it is questionable whether the rules concerning reentry are applicable in this case, since the ascent to outer space itself was only executed to provide the initial potential energy.[20]

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[19] Pogies, 2021.

[20] In the case of a hypersonic glide starting with sustained orbital spaceflight, the orbits are typically used for prepositioning the vehicle to the appropriate position in space and time for a successful hypersonic flight.

2.2. Suborbital Spaceflight

The core challenge with suborbital spaceflight is that it is easy to misunderstand. The “sub” part of the word suggests that suborbital flights are happening below the orbital regime, but this is not necessarily true. Suborbital flights do not complete a full orbit around the Earth. There can be several reasons for this.

First, it is possible that the flight does not reach an altitude where sustained orbital flight is possible (in which case, the flight is very much comparable to the mesospheric flights described in Section 2.1.). Second, it is possible that that the vehicle does not have enough kinetic energy to complete the orbit (the scalar value of actual vehicle velocity is below the scalar value of orbital velocity of the respective trajectory), even if it reaches altitudes where orbiting spacecraft usually operate. This is the situation during, for example, military intercontinental ballistic missile launches. Third, even if the scalar value of actual vehicle velocity is over the orbital velocity, and the combined energy of the vehicle is enough for orbiting, the vehicle cannot complete an orbit if the actual velocity vector points in a direction that is inconsistent with orbiting (an extreme example is the directly vertical direction during the active part of the launch). Potential examples for this trajectory include scientific launches into the Van Allen Belts (to record a vertical cross-section of the radiation environment) or direct-ascent antisatellite weapons against medium (or higher) Earth orbit satellites.

Currently, suborbital flights are usually used for scientific research, technology development, military (ballistic missiles, ballistic missile defence, and antisatellite weapons), and commercial purposes, including human suborbital flights reaching over 100 km (Virgin Orbit and Blue Origin). Nonmilitary flights usually start and end in the same country or in international waters.

However, there is an emerging application of point-to-point transportation of goods and people (e.g. the SpaceX Starship P2P,[21] also known as Starport Network). During a suborbital point-to-point delivery flight, the vehicle launches onto a ballistic trajectory, leaves the dense atmosphere, transits the volume where spacecraft typically operate, reenters the dense atmosphere, and lands (practically, the same trajectory on which military intercontinental ballistic missiles fly). During this flight, the vehicle is expected to fly over the territory of more than one country. The trajectory transects the air volume typically used by not only conventional aircrafts but also orbiting spacecrafts. However, it is not clear whether the atmospheric flight sections correspond legally to space launch and re-entry (although technically they do) and whether the high-altitude coast corresponds legally to spaceflight (although technically it does).

Practically, it is possible to complete a suborbital flight by launching from international waters or airspace, transiting over countries above the dense atmosphere, and then re-entering over international waters. Such a flight would be completely

[21] Wilken and Callsen, 2023.

outside sovereign national control if the exoatmospheric flight section is considered spaceflight. While international controls do exist,[22] there are no enforcement mechanisms related to these controls.

However, if the exoatmospheric flight is not considered spaceflight (e.g. if the delimitation is based on a functionalist approach requiring completed orbit), this flight again falls under the Chicago Convention, but without any practical means for the state to execute its sovereign rights (e.g. Article 10 of the Chicago Convention[23] established a right for states to require the landing of overflying aircraft at a designated customs airport, which would be practically impossible in the case of a suborbital vehicle).

2.3. Flights that Alternate between Different Flight Regimes

The combination of orbital or suborbital exoatmospheric flight and endoatmospheric aerodynamic flight is not new. It was proposed by Eugen Sänger and Irene Bredt, engineers working in Germany in the 1930s. Their system, called Silbervogel,[24] was based on a hybrid winged and lifting body airframe that launches on a suborbital energy trajectory and reaches altitudes between 100 and 200 km (several trajectories were computed by the designers, and the mentioned values can be found for flights with intercontinental reach and practical payload weights). Then, the vehicle starts its descent; in the denser atmosphere, it uses its lift-generating surfaces to achieve a positive climb again (sacrificing kinetic energy), and it starts another climb but with a lower maximum altitude. Ultimately, the vehicle reaches its destination with several hops, each lower and shorter than the previous. With enough initial energy, the vehicle is computed to be able to circumnavigate Earth.

Many similar designs were developed in the decades following the Second World War, in both the Soviet Union and United States (US). Generally, these designs are called boost-glide vehicles. All those utilising these vehicles fell victim to their lack of necessary technology required, but they also lacked any appropriate business case or military operational need.

Similar principles were considered during the Apollo lunar programme for use during atmospheric reentry from the direct trans-Earth trajectory from the Moon (called skip reentry). Ultimately, while skip reentry became unnecessary, it was used during the design of the Orion spacecraft and the Artemis programme's lunar return trajectory design to limit the heat load on the capsule's thermal protection system. Skip reentry was also used by the Soviet and Chinese Moon probe returns to enable increased manoeuvrability during reentry.

All the previously designed or flown boost-glide or skip reentry vehicles were unpowered after the initial launch or (in the case of lunar spacecraft) after trans-Earth

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[22] Sipos, 2018.

[23] ICAO, 2006, p. 6.

[24] Sänger and Bredt, 1944.

injection. However, it is not impossible to combine the boost-glide trajectory with rocket or scramjet propulsion, thereby combining the previously mentioned hypersonic lift vehicles with the boost-glide principle. Such a vehicle would launch on a rocket, reach exoatmospheric altitudes, and coast (or even orbit) there. Descending into the denser atmosphere, it would use atmospheric lift to increase its altitude (potential energy) and use its engines to replenish the kinetic energy lost during the climb.

To effectively coast between the climb sections, the vehicle needs to reach an altitude of at least 130–150 km to minimise drag, or even the altitude usually occupied by orbiting spacecraft. However, to generate enough lift and operate the scramjet engines (scramjets are air-breathing), it needs to descend deep into the mesosphere. Note that during the lift sections, the lift vector can be oriented to the left or right of the flight path, to enable steering (this manoeuvre is routinely used during spacecraft reentry).

By combining the technical questions of mesospheric hypersonic flight and suborbital exoatmospheric flight, this technology effectively combines the legal problems as well. The boost-glide vehicle can circumnavigate Earth, but this is not a Keplerian orbit. It reaches altitudes usually associated with spaceflight but spends a significant amount of time in the denser atmosphere (mesosphere) too. It transits the airspace used by conventional aircraft and by launching or re-entering spacecraft, but these transits are not space launches or re-entries. Finally, by using engine thrust and manipulation of the lift vector, the boost-glide vehicle can execute manoeuvres impossible for spacecraft, and while it uses the denser atmosphere for this, it cannot land at will at the usual airports to comply with the orders of national authorities for inspection and customs procedures.

2.4. Section Summary

In this section, I introduced three emerging and potentially disruptive technologies that ride, both physically and legally, the imaginary fence between airspace and outer space.

The three technologies – hypersonic flights in the mesosphere, suborbital point-to-point flights over long distances, and boost-glide flights – share some common questions about the lack of legal controls:

- They are not spaceflights as it is commonly understood; however, they reach altitudes outside the denser atmosphere usually associated with spaceflight and used by orbiting spacecraft.
- A significant amount of the flights’ operational time is spent in the mesosphere, a region that is usually not considered as outer space; however, their interaction with the atmosphere is different from the way conventional aircraft interact with the atmosphere. These atmospheric flight sections are not space launches or re-entries. The vehicles are physically incapable of

  complying with the rules set in Article 10 of the Chicago Convention, while at the same time, the states are usually incapable of enforcing compliance.
- When the necessary technology is developed (mainly scramjet propulsion and structural and thermal protection materials), these vehicles will be capable of alternating between endoatmospheric and exoatmospheric flight without entering orbit or finishing their flight in the denser atmosphere.

The lack of commonly understood and legally binding delimitation of airspace from outer space makes it impossible to develop operational rules, regulations, and guidelines for these technologies. As demonstrated earlier, it is possible to execute such flight operations by completely staying out of national controls. Moreover, with the proliferation and commercialisation of space and space-related technologies, manufacturers and operators are practically capable of performing these flight operations, and their compliance (in extreme cases) will be expected to be strictly voluntary.

It is desired that the international legal community, in cooperation with the manufacturers and operators, develops rules and regulations concerning these technologies. It is also recommended that these regulations create an intermediate zone above the volume where conventional air operations occur and below the volume where conventional space operations occur. There are initiatives for a similar zone in the stratosphere to regulate the traffic of high-altitude platform stations (stratospheric aerostatic and aerodynamic aircraft) above the volume used by conventional air traffic. This zone is planned to be based on physical delimitation, at a preset altitude around flight level 550 or 600 (roughly 17 km above the main sea level).[25] Similarly, a preset altitude can be selected, possibly around 150 km, to serve as the upper limit. This altitude is based on McDowell's[26] recommendation of 125 km (lower limit of sustained circular orbits), but it is extended upwards to account for the dynamic nature of the upper atmosphere. Similar volumes have already been advocated for, and J.N. Pelton's[27] proposal of the proto-zone[28] between 21 and 160 km is widely discussed but is, of course, not codified. From the operational point of view, such a designated intermediate volume would be beneficial.

It is also necessary that, following the establishment of the intermediate zone, an international convention develops a set of rules – which are comparable to the Chicago Convention and its relevant annexes (about the rules of flight operations in international airspace) – about operations in this new intermediate zone and the interaction with the airspace below and outer space above.

Defence-related applications of these technologies include weapons delivery, reconnaissance, and transportation of troops and supplies. All of these can be

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[25] EASA, 2023.

[26] McDowell, 2018.

[27] Pelton, 2016.

[28] Alternative spelling: protozone.

very sensitive issues in international relations. This underlines the necessity of legislation.

3. Questions of the Sovereignty in Outer Space

The Outer Space Treaty clearly mentions that state sovereignty cannot be applied to any volume of outer space (Article II); at the same time, it specifies that states are responsible for the operation of their spacecraft (Article VIII). These two rules combined dictate that state sovereignty applies to the outside parts of the spacecraft, and ends there. Outside the physical body of the spacecraft, the volume of outer space is free for exploration and use.

Orbital mechanics dictate that spacecraft in orbit are moving. This practically means that the orbiting spacecraft occupies a given volume for an infinitely short amount of time; then it moves on, and the previously occupied volume is available again for free use by other space actors. It is the responsibility of spacecraft operators to ensure that no two spacecraft occupy the same volume at the same time (which would mean a collision).

Practical considerations related to space surveillance, spacecraft tracking, and navigation make this theoretical situation somewhat unclear. Spacecraft are not tracked with absolute certainty, and there are always errors in the measurements and predictions; therefore, operators consider elliptical volumes around their respective spacecraft as the basis of collision-avoidance manoeuvres.[29] The size of the elliptical volume directly depends on errors in the measurements, and it is generally accepted that these volumes are not "occupied" by the spacecraft and are subject to change according to the sensor properties and the advance of technology. However, this can cause misunderstandings when two operators, working with orbital element sets with different error levels, disagree on the probability of a potential collision and the necessary avoidance manoeuvres. Therefore, only a universal space traffic control system can provide adequate general answers to this problem.

3.1. Limited-Use Zones in Space Operations

In addition to the aforementioned virtual volumes, there exist (or are planned to exist) zones around spacecraft that are physical reality and are (planned to be) used to control the interaction of spacecraft. One example is the set of approach rules to

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[29] During rendezvous and proximity operations, where absolute certainty is necessary, onboard sensors are used for more precise measurements and manoeuvre planning.

the ISS,[30] the other is the safety zone concept described in the Artemis Accords.[31] We can safely assume that with the proliferation of human presence in Earth orbit and cislunar space and the advancement of uncrewed space vehicle approach and manoeuvring technologies, many more similar rules about operational safety zones (as they can be collectively called for practicality) will be written. These rules describe the procedures and limitations to be observed during approach to the respective space objects. However, these are not universal regulations, but commonly agreed rules binding only the respective parties. Noncompliance with these rules is to be dealt with by the parties to the agreements.

It is unclear, however, how the breach of such an operational safety zone by an outside actor can be dealt with. For a theoretical case study, let us assume that a highly agile and manoeuvrable spacecraft of an identified operator that is not a party to the ISS agreements and memorandums enters the operational safety zone around the ISS. This spacecraft is under continuous control of its operator, was not identified as a collision risk before the approach manoeuvre (because of which ISS did not execute collision-avoidance manoeuvres), and is keeping a stable distance from the ISS after entry into the zone without posing any direct risk. However, its presence still disrupts the ongoing operations of the station.

It is clear that the agreements defining the operational safety zone do not apply to the operator of the intruding spacecraft. This operator would declare that, under the Outer Space Treaty, the manoeuvre was an innocent free use of outer space, and that the spacecraft was capable of safely operating in close proximity to ISS and not causing any harm. The same case can be applied to an intrusion into the safety zone around a lunar installation of a party to the Artemis Accords by an outside actor.

Since the case reaches a dead end here under the Outer Space Treaty, there is a risk of creating a "new normal" when such intrusions continue. Diplomatic actions and international pressure can (and surely would) be applied to mitigate the situation. However, in my opinion, under the current international space legal framework, further sanctions are not possible.

3.2. Noncooperative Rendezvous and Proximity Operations

This case is a generalisation of the previous one. Operational safety zones are defined according to the current best understanding and best practices related to orbital operations, and they are specific to the respective few spacecraft or, in the case of the Artemis Accords, lunar installations. However, with the advancement of technology, noncooperative approaches to rendezvous and to fly in formation with any spacecraft are currently possible or will be in the near future. Even if such an

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[30] The approach procedures are described in detail in the 'ISS COTS Interface Requirements Document SSP50808', which is controlled by the International Traffic in Arms Regulations (ITAR). For an excerpt that falls outside ITAR controls, see: DuPont, 2005.

[31] Schingler, 2020.

approach does not end with contact or collision, it can still disrupt the normal operation of the target spacecraft.

There are several reasons related to military or national security activities for why an uncooperative rendezvous and proximity operation might be beneficial from the point of view of the operator of the approaching spacecraft. The clearest reason is to preposition a kinetic antisatellite weapon[32] for a strike with a relatively short timeline. However, a close approach can enable electronic warfare (signal intelligence or jamming) activities with different attack geometries from those executed from the surface;[33] it also enables close inspection of the spacecraft with various sensors[34] and harassment.

At the same time, there are (or planned to be) numerous peaceful applications for this technology. The most well-known are space station resupply (and by extension, logistics related to uncrewed in-space manufacturing stations), orbital servicing (operational lifetime extension),[35] space debris removal,[36] and in-space construction.

The operator of the target spacecraft can only blindly trust that the approaching spacecraft is capable of safely executing the approach, rendezvous, and proximity operations, and that the operator of the approaching spacecraft does not have harmful intent. Therefore, the operator of the target spacecraft can utilise one of the following measures:

- Do nothing. However, in this case, the target spacecraft becomes a sitting duck.
- Perform preventive avoidance manoeuvres. In this case, operations of the target spacecraft get disrupted, and its operational life is shortened because of the unplanned spending of fuel.
- Call for public attention and the application of soft power. In this case, the operator of the approaching spacecraft can assert that the approach is simply an innocent free use of outer space and portray themselves as victims.
- Execute active measures to prevent the approach. In this case, the operator of the target spacecraft becomes the aggressor, since the approaching spacecraft has not yet performed anything that is harmful and not a free use under the Outer Space Treaty.

Altogether, the main problem with this current unregulated situation is that these “tailgating” operations can create a “new normal” where deviation from the previously understood (unwritten) behaviours become accepted just because they are performed many times. Successful rendezvous and proximity operations had already

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[32] A historical example is the Soviet IS antisatellite weapon system. For a description, see: Zak, 2024.

[33] A historical example is the US electronic intelligence satellite series under various cover names. For a description, see: rob1blackops, 2017.

[34] A historical example is the US Geosynchronous Space Situational Awareness Program satellite series. For a description, see: *Geosynchronous Space Situational Awareness Program*, 2020.

[35] ESPI, 2020.

[36] Aglietti et al., 2020.

been performed at the time when the Outer Space Treaty was codified (during the Gemini 6–7 flights in December 1965); therefore, it would have been possible to regulate them before they became commonplace.

3.3. Declaration and Enforcement of Security Zones Around Spacecraft

This section takes the cases described in the previous sections further by combining them. Considering the operational and security risks related to uncooperative rendezvous and proximity operations, a spacecraft operator can find it beneficial to declare a volume around their spacecraft to not only ensure safe and effective operations (as described in Section 3.1.) but also keep unwanted visitors away to prevent the harmful actions described in Section 3.2. The two unanswered questions related to this are whether such a declaration can be legal, and how such an exclusion can be enforced in the case of a breach into the security zone.

The declaration of a security zone can be similar to a declaration of an air defence identification zone (ADIZ). An ADIZ

> …serves as a buffer between international airspace and a country's territorial airspace…. Establishing such a zone allows a country to better monitor air traffic flying near its airspace and respond to aircraft that fly close to its airspace before the aircraft actually enter the airspace. Although such zones are not recognized as sovereign airspace by international law, it is customary for foreign aircraft entering such zones to identify themselves and seek prior authorization from the country controlling the zone before entering.[37]

However, an important difference between a space security zone and an ADIZ is that the ADIZ is a continuation of sovereign airspace, while a space security zone can only be the continuation of the internal physical volume of a spacecraft. During ADIZ operations, air defence forces of the country operating the ADIZ routinely fly out of sovereign airspace into international airspace to identify aircraft. Noncompliance with ADIZ rules[38] can only result in administrative actions before the noncompliant aircraft enters the sovereign airspace of the country (where the rules enforceable are not ADIZ-related but related to the military protection of sovereignty). At the same time, a declared space security zone, without the accompanying sovereign airspace where active measures are possible and legal, would be practically meaningless.

Still, we have seen and are seeing technological activities related to the enforcement of rules and active denial of navigation around spacecraft. The Soviet

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[37] Trent, 2020.

[38] ADIZ rules typically require the filing of a flight plan, establishment of radio communications, use of automatic identification datalink systems and visual identification means, and compliance with the orders of the ADIZ administrator.

space station Salyut 3[39] carried the Rikhter R-23 23-mm compact aircraft cannon. The sole purpose of such a weapon on a spacecraft can be to provide the capability of firing upon another spacecraft. Considering the limited manoeuvrability of a space station, the only realistic use can be self-defence, that is, the destruction or disablement of an approaching spacecraft. Recently, France announced the plan of deploying small-size satellites equipped with lasers and kinetic weapons, as well as onboard weapons on the large satellites themselves to protect their military and national security missions' vital space infrastructure.[40]

According to the French announcement, these active protection measures could and would be used only when the hostile intent of the approaching spacecraft has been proven beyond doubt. However, this is questionable from a technical and practical point of view. The root of the French initiative was the approach and stationkeeping executed by the Russian Luch-Olymp electronic warfare satellite with the jointly operated French-Italian Athena-Fidus military telecommunication satellite.[41] The Luch-Olymp is equipped with radio receivers and is capable of intercepting signals directed towards its target satellite from the ground.[42] However, considering a typical uplink antenna beamwidth of 1.5 degrees and the distance between the communication satellite and uplink station of 40,000 km, the uplink station illuminates a circle with a diameter of roughly 1,000 km. Therefore, the Luch-Olymp only needs to approach its target within 500 km. Even with an extremely tight uplink antenna beamwidth of 0.3 degrees,[43] a 100-km approach is sufficient to intercept the signals. Stable stationkeeping at this distance is not a direct threat, but it is entirely sufficient to complete the mission.

Practically, these patrol systems could only be useful if they are used to prevent the approach into a predetermined volume around the spacecraft they protect; without that, the systems are purposeless in my opinion. With the spacecraft security zone declared, these patrol spacecraft can have the defensive depth to act. Therefore, the case falls back to the question of whether the declaration of a spacecraft security zone, within which the spacecraft operator (with the patrol spacecraft) can have the means to enforce restrictions on free navigation, is the declaration of a sovereign volume in space or not.

An analogy can be called for assistance – that is, the history of territorial waters, specifically, the cannon-shot rule. This is expressed as, '*Potestas terrae finitur, ubi finitur armorum vis*', which is translated as 'Power over the land ends wherever

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[39] On orbit between 25 June 1974 and 24 January 1975.

[40] Lye, 2019.

[41] Roberts, 2022.

[42] Given the directional nature of the usual satellite uplink antennas, such signal interceptions are not possible (or at least not effective) when done from the surface or aircraft.

[43] This is the -15 dB beamwidth of the GD Satcom 9.0m Cassegrain antenna at Ku band. The onboard receivers of a signals intelligence satellite are capable of compensating the signal loss compared to the -3 dB beamwidth commonly used in telecommunication link design calculations.

the force of arms ends'.[44] This practically means that state control over coastal waters extends as far out as the effective range of the coastal defence artillery. This somewhat vague definition was practically understood as 2–4 miles as measured from the shoreline.

The two situations can be easily compared. Both cases involve a physical location over which state control is undisputed. This is the land area of the state in the territorial waters' case and the internal physical volume of the spacecraft in the spacecraft security zone. From this location, a zone is extended outwards to the limit of the range of destructive capabilities the state can use, under its own sole discretion, to destroy or disable any craft that does not comply with the rules this state declares about navigation in the zone. Lasers or kinetic weapons carried by satellites are analogous to the coastal defence artillery protecting territorial waters. Their range, destructive capabilities, mode of employment, and employment itself are solely determined by the state that deploys the weapons. Based on this analogy, a unilaterally declared spacecraft security zone is in essence similar to the historical declaration of territorial waters; therefore, it is a declaration of sovereignty over a volume in outer space.

3.4. Section summary

This section examined the problems related to controlled access zones in outer space. From a practical point of view, the universal free access and freedom of navigation described in the Outer Space Treaty is not feasible. First, these are hardly possible with the current state of the technology. Second, and in my opinion more important, the age of trust between spacecraft operators (that existed during the early days of spaceflight) has come to an end. It is practically possible to approach any space object using another spacecraft. The real capabilities of the approaching spacecraft can stay hidden until they are actually employed, and this poses risks or even threats to the target spacecraft. The current legal regime does not provide rules or tools to mitigate these other than manoeuvring of the target (if it is capable of manoeuvring). This raises a question that is just as ethical as practical: Why should the target spacecraft subject itself to perceived coercion instead of having the right to stand its ground, deal with the threat, and continue to operate safely and securely?

There are regulated access zones operated or planned around space objects nowadays. However, these regulations apply to only those that are party to the agreements that established these zones and are not directly enforceable. Safe operation of these space objects depends solely on the good faith and voluntary professional behaviour of other operators.

The source of these risks and threats is the capability of approaching and stationkeeping with any space object by spacecraft with sufficient manoeuvring and

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[44] For the source of the quote and translation, see: Fellmeth and Horwitz, 2011, paras. 1–2.

navigation capabilities. This technology is not new, but its proliferation and automation makes this situation more severe.

We have often observed approaches to and co-orbital manoeuvring with uncooperating spacecraft. This technology can just as well be used for peaceful purposes as for hostile acts. The spacecraft systems necessary for one application group are just as usable for the other. For example, a space debris removal spacecraft needs very precise instruments to determine the movements and physical outline of the target debris, precise and agile manoeuvrability to approach, a grappling and manipulation toolset, and finally enough reserve orbital manoeuvring capability to physically remove the target debris to an appropriate disposal orbit. The very same onboard systems are necessary for a co-orbital anti-satellite system that is capable of observing as well as damaging or disposing of operational satellites during a conflict.

Therefore, it is understandable that operators of high-value satellites, which are considered critical national infrastructure or military mission vital infrastructure, plan to protect their spacecraft with real physical means. There are detailed arguments about how the UN Security Council or the belligerents could do this during conflicts.[45]

However, in the age of nonlinear and hybrid warfare,[46] the timeline and legal background for such a resolution or declaration are inappropriate. To start with, the UN Security Council can only adopt a draft resolution by affirmative vote of nine of the fifteen members and no veto from any of the five permanent members. Considering that three of the five permanent members (China, Russia and the US) currently possess spacecraft capable of noncooperative co-orbital operations for intelligence activities, along with the Security Council's ineffectiveness related to the Ukraine-Russia war (where one belligerent is a permanent member and is therefore capable of vetoing any draft resolution directed against its own interests), it is highly unlikely that such a resolution would be adopted during an actual conflict. Moreover, the very nature of hybrid operations is that the use of kinetic military means is just one part of the portfolio to be used by the aggressor. Most of the hybrid operations toolset is non-kinetic and below the threshold of conventional aggression.[47] This makes it very hard for the targeted operator or state to argue for a resolution.

It is argued that, to prevent a surprise attack and limit the effectiveness of intelligence gathering about the satellite, security zones should be created around spacecraft outside the time of conflict (or a different understanding is that the conflict is permanent and is actually ongoing even now). Such spacecraft security zones are meaningless without their enforcement, for which there is no existing international framework. However, individual enforcement of these zones is directly comparable to enforcement of the sovereign rule of territorial waters; that is, it practically equals

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[45] Stubbs, 2021.

[46] Reichborn-Kjennerud and Cullen, 2016.

[47] Treverton et al., 2018.

the declaration of sovereignty over a volume of outer space, which is contrary to the Outer Space Treaty.

It is desired that the international legal community, together with spacecraft manufacturers, operators, and space tracking service providers (both state and private organisations), develop a set of rules and regulations that are universally applicable to approach, rendezvous, and proximity operations. These rules must be tied to the existence and operation of the spacecraft itself and not to the operator or the state that registered it. This way, questions about sovereignty can be avoided. It must be noted, however, that enforcement of these rules remains unresolved.

Regulation of the rendezvous and proximity operations is not as hot a topic in international discussions as the question of destructive direct-ascent antisatellite weapons. However, in my opinion, considering the multiple-use nature of co-orbital operations and the possibility of below-the-threshold coercive applications, this regulation is even more important that the aforementioned debates and decisions about destructive antisatellite weapons.

4. Orbital Operations and the Status and Value of Space Objects

A spacecraft is valuable property. It can provide essential services and valuable scientific insights as well as be a key component in the defence and security framework of a nation. At the same time, defunct spacecraft or remnants of rocket bodies are considered drifting hulks and debris. However, on-orbit technologies (on-orbit servicing and manufacturing) can change this view. Launching masses of material into space is expensive, and the material already there is valuable.

On-orbit servicing missions can extend the life of orbiting spacecraft that lost some necessary capability to safely operate, such as their manoeuvring (stationkeeping) fuel,[48] power generation,[49] and attitude determination and control[50] capabilities. On-orbit servicing can reconstitute these capabilities. Modular spacecraft (typically, space stations and the Hubble Space Telescope) can also be repaired and

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[48] Various forces act on spacecraft, changing their orbits from their nominal mission orbits to unusable, even dangerous ones. Stationkeeping counteracts these perturbing forces to maintain a nominal mission orbit, and manoeuvring changes the orbit to adapt to new operational requirements. From the perspective of orbital dynamics, the two are similar. When the fuel usable for manoeuvring or stationkeeping is exhausted, the satellite cannot continue its services.

[49] Most spacecraft use solar power as an on-orbit energy source. The semiconductor solar panels and chemical batteries get degraded during operation. When the power generation and storage capabilities fall below the level required by the spacecraft systems, the services need to be limited or ended.

[50] To orient sensors or antennas, most satellites measure and control their orientation in space precisely. Without this capability, service provisioning for such satellites is not possible.

upgraded. With on-orbit maintenance, an inoperable satellite can be restored to being operational again with the investment of fewer resources compared to the launch of a new satellite. Finally, with in-space manufacturing complexes, it will be possible to recycle the material of space objects that are unfit for further use.

Differentiation between an operational spacecraft and a drifting hulk is not necessarily easy. Spacecraft can have many functions, and it is possible that these functions' operations do not cease at the same time. In extreme cases, even a spacecraft that completely lost its active functions can serve useful functions. One example is the Hungarian SMOG-1 picosatellite. This spacecraft carries an experimental material that interacts with the geomagnetic field to accelerate orbit degradation without requiring any power or control.[51] This experiment lasts for years, possibly up to a decade, during which all communications, control, computing, and power generation systems of the satellite are inoperational, but the satellite as a whole still executes one of its designed missions. Therefore, from a physical point of view, it is a drifting hulk no different from any other dysfunctional satellite or rocket body. However, from the operational point of view, it is a component of a technology experiment.

4.1. Operational and Inoperational Spacecraft

The Outer Space Treaty, the Convention on Registration of Objects Launched into Outer Space,[52] and the Convention on International Liability for Damage Caused by Space Objects[53] describe the rights and responsibilities of those who launch and operate space objects. They specify that the responsibility for safe and professional operation and for the damage caused by space objects is created by the launch (or launch attempt). According to Article VIII of the Outer Space Treaty, ownership of a space object is not affected even by its return to Earth, but it can be safely said that disintegration of a spacecraft in the atmosphere or during its collision with the surface means that the object ceases to be a space object.

The launching state is responsible for the damage caused by the space object. However, the practical application of this provision is not necessarily clear. During the early years of space activities, the number of space objects and their density in the volume of outer space made it highly unlikely that two uncontrolled space objects will collide before their orbits degrade into the atmosphere. As the advancement in technology trended towards more and more manoeuvrability and control, it could have been safely assumed that careful control of spacecraft would negate the risks of collision in the future.

As it turned out, the situation is entirely different. No fully reusable launch vehicles are yet developed, and therefore every space launch results in re-entries of

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[51] Alba Orbital, 2020.

[52] UN General Assembly, 1975.

[53] UN General Assembly, 1972.

stages that are not controlled, or the level of control is limited. A large part of the satellites launched nowadays (typically, smaller spacecraft) do not carry propulsion for orbit maintenance or collision avoidance.[54] These satellites are incapable of any action that could prevent a collision with another space object or property on the surface or in the airspace. Moreover, the onboard communication and identification systems (if there even is an identification system)[55] will usually reach the end of their lives much before the satellite reenters the atmosphere for final disposal. From here on, these satellites, of which hundreds are launched every year, are (according to the Outer Space Treaty and Liability Convention) still the responsibilities of their respective launching states, even though said states might have no means to track them (the capability of accurate space object tracking is not a legal prerequisite of a launch) and have absolutely no means to manoeuvre them. Moreover, as we have seen, such a space object can even be part of an active space utilisation project.

Therefore, according to the existing space legal regime, launch of a space object creates a responsibility that can last for decades, centuries, or even longer.[56] During a significant portion of this time, the launching state has no practical means to do anything to fulfil this responsibility and can only watch as the situation unfolds. The value lost in the case of a collision is highly dependent on the whether the satellite is operational, but right now, there are no objective guidelines to determine this, and the only source is the statement of the operator.

The only case up to now when a collision of an operational satellite with an in-operational one caused significant physical and monetary damage was the collision of Iridium 33 and Kosmos 2251.[57] Kosmos 2251 was a Strela-2M-class military telecommunications satellite. This type of satellite did not carry manoeuvring thrusters for orbit maintenance, collision avoidance, or (most importantly for our case) safe planned deorbit. The satellite ceased functioning in 1995 and was freely orbiting (on average) 800 km above the Earth surface, from where natural degradation can take many decades. Iridium 33 was a commercial telecommunications satellite operated by Iridium. Iridium satellites orbit at the same average altitude as the Kosmos 2251 did but carry manoeuvring thrusters, and the satellite was fully capable of executing the necessary orbit change to avoid the collision. However, the predictions available

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[54] Satellites of larger physical size and higher value typically carry manoeuvring thrusters for orbit maintenance and collision avoidance. In the case of a predicted collision between a satellite capable of an avoidance manoeuvre and another that is not, it is logical that the first does everything necessary to minimize the chance of any contact, even if it means the expenditure of its manoeuvring fuel (and therefore its lifetime).

[55] The Orbital Whereabouts Locator (OWL) developed by C3S Ltd. is one example of an identification and tracking subsystem for small satellites. For technical and operational information about OWL, see C3S Electronics Development LLC, 2023.

[56] The natural atmospheric drag removes the space objects within a few years from the lower volume of low Earth orbit. However, above the 1,000 km altitude, the drag becomes minimal, and the natural degradation takes at least decades. From medium Earth orbits and the geosynchronous altitude, natural forces can never remove the space objects.

[57] Weeden, 2009.

to Iridium, based on public space tracking data, did not indicate a potential collision, only a close approach. The closest predicted approach was 117 m, which, while concerning, is not necessarily dangerous,[58] and subsequent predictions showed greater distances.[59]

Following the collision, many legal analyses have been published concerning the Liability Convention, which examine in detail the questions related to the event. As it turned out, even the applicability of the Liability Convention was questionable,[60] considering that Kosmos 2251 and Iridium 33 were both launched by the Soviet Union or its successor states (Iridium 33 was launched onboard a Russian Proton missile from Baikonur, Kazakhstan). My main concerns here are the questions of fault and duty.

To determine liability, first, the party who was at fault must be determined. Moving away from the actual case of the Iridium 33-Kosmos 2251 collision and generalising it as the collision of two generic satellites with similar capabilities, the determination of fault becomes very difficult.

Kosmos 2251 was completely passive, incapable of any collision avoidance or reporting of its position. However, it had ceased to execute its original functions 14 years before the collision and had no reason to be in space anymore. It was there because it was left there, knowingly abandoned by its operator. The only publicly available reliable source for its orbit was the public directory maintained by the US government; however, the accuracy of this information was known to be low. At the same time, it was known that the US government had more accurate orbit data but kept it highly classified. It can only be speculated that the Russian government had more accurate orbit data from its own space tracking systems.

The Iridium 33 was operating actively and was capable of manoeuvring; its radio emissions could have contributed to its tracking, in addition to the tracking data published by the US government. It had every reason to be present in space, and Iridium usually removed the satellites at the end of their useful lives by using the onboard thrusters (unless a satellite suffered a malfunction that rendered it uncontrollable). However, Iridium had no means to accurately predict that the collision was inevitable. Moreover, it was possible that a manoeuvre itself would create the geometry that led to a collision because of the uncertainties.

The question is, when does the chain of actions or inactions leading to the damage start? Is the launching state at fault because it knowingly launched a satellite that cannot be removed from orbit and might cause a collision decades or centuries later? Is the launching state at fault because it knowingly launched a satellite without accurate orbital surveillance capabilities to determine the relative path of other objects for the future planning of avoidance manoeuvres? While these technical challenges

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[58] Because of a lack of indirect effects such as a pressure wave, any approach that does not result in a direct contact is harmless.

[59] Kelso, 2009.

[60] von der Dunk, 2010. p. 201.

could actually be overcome, the ultimate challenge of final removal from orbit is often impossible to solve.[61] Considering the cislunar and interplanetary trajectories, the problem of abandoned spacecraft will be even more concerning because of the lack of space object tracking services.

4.2. Orbital Debris Removal

Since it is often impractical to install propulsion on a spacecraft to facilitate final removal from orbit, a business idea is growing nowadays to do the removal using specialised spacecraft.[62] These spacecraft need to be highly manoeuvrable and have adequate reserve fuel, sensors for precise approach and station keeping, and grappling manipulators to physically connect to the target satellite.

The timeline of an orbital debris removal mission can be envisioned as follows: The removal spacecraft is launched onto a suitable rendezvous trajectory (from either the ground or a storage orbit). It executes a rendezvous with the target and starts proximity operations to determine the actual status of the target and match relative movements and positions to set up the final approach geometry. Then, the removal spacecraft approaches the target and uses its grappling manipulator or other connecting device to attach itself to the target. The removal spacecraft then places itself and the attached target onto a transfer orbit towards the final disposal site. This final disposal can only occur by collision with a celestial body that removes all parts of the spacecraft from free orbital flight. Practically, in the Earth orbital region, an atmospheric reentry is a suitable final disposal. Reentry into other planetary atmospheres is also appropriate. A multi-mission-capable removal vehicle can detach from the target after the disposal manoeuvre to propel itself onto a storage orbit for its next mission.

In addition to this propulsive deorbit, other methods are being developed that do not require physical contact, such as directed energy effectors (laser brooms).[63]

Some space missions are already planned with this approach in mind. For example, satellite communications company OneWeb announced its partnership with

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[61] The energy required to remove a satellite from higher orbits is equal to the energy necessary to launch there from a lower orbit (where natural forces would remove them within a short timeframe). The following example uses a typical launch sequence used by Sea Launch during its operations (Sea Launch ceased its operations in 2014, after the conflict between Ukraine and Russia started, but it is used now because the equatorial launch did not require a plane change manoeuvre, and the energy requirement of the plane change is irrelevant now). The launch vehicle lifted the upper stage with a payload onto a roughly 200-km circular parking orbit. After the phasing coast, the upper stage changed the orbit into a Hohmann transfer trajectory (geostationary transfer orbit). Reaching the geostationary altitude, the upper stage or the payload itself circularised the orbit. The energy expended during the circularisation would be required again to put the end-of-life satellite onto a similar transfer orbit into the atmosphere. While this is technically not impossible, it is economically inviable.

[62] *Top Space Debris Management Startups*, 2024.

[63] Hedglin, 2018.

Astroscale to execute a removal mission and has incorporated grappling fixtures into the satellite design.[64] While OneWeb satellites can manoeuvre on their own and have designated reserve fuel for deorbit, this grappling fixture allows an independent-party spacecraft to safely handle the satellite in case of a failure.

Operators and service providers can handle liabilities and responsibilities in the contract they sign for the removal service. The situation becomes more complicated when an abandoned spacecraft needs to be removed. Of course, no spacecraft is truly abandoned, since the launching state always has liability and responsibility, but private operators can suspend their activities or go out of business, leaving uncontrollable drifting objects in orbit. In this case, it is unclear who has the right to act on the one hand and who is required to act to remove a space object on the other. When the technology becomes widely available, removal of the inactive space objects will be an effective way to keep space operations sustainable, especially in the low Earth orbit and geostationary orbit regions. In addition to the general cleanup of valuable orbital paths, emergency actions will be possible to prevent collisions.

There can (and will) be several events when time will be of the essence. A debris-generating collision in the higher regions of low Earth orbit, and especially in the geostationary orbit region, could pollute the region for centuries or longer. Cascading events (collision of debris pieces or collision of a debris piece with a third-party satellite) could prolong and increase the problem, and prevention of these cascading collisions in the most fragile regions is of utmost importance. The Liability Convention contains provisions about third-party damage; however, the main problem is pollution of the orbits. Space debris removal technologies will be able to prevent such collisions, even between unmanoeuvrable spacecraft, be they abandoned drifting hulks or operational satellites without propulsion. Numerous questions arise from this capability.

The first question comes from the uncertainty of the prediction of collisions. Only when two space objects come in physical contact can anyone be absolutely sure that the problem is real; however, any action is already late at this point. Up to the collision, the necessity of any action can be disputed. The operator of a spacecraft cannot be forced to enlist a space debris removal service to move their spacecraft, taking up the risks associated with such an action. Any external influence (an outside party, e.g. a state agency executing the manoeuvre) can be considered as a damaging action.

The second question comes from the future effects of the movement of the space object onto a different orbit. Up until the manoeuvre, it can be assumed that the spacecraft operator (ultimately, the launching state) is responsible for the consequences of the existence of the space object. However, the removal or collision avoidance manoeuvre introduces a variable most likely outside the control of the original operator. Again, when this removal or avoidance manoeuvre is done under a contract, the transfer of responsibility can be arranged between the parties. Nevertheless, when the manoeuvre is executed by an outside party to keep the orbits safe from a predicted potential collision, this transfer is uncertain.

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[64] Spacewatch.global, 2019.

4.3. Chain Event Effects and Indirect Consequences

With the number of space objects dramatically going up in the low Earth orbit region and the unsolved problem of final removal of abandoned satellites in the geostationary orbit region,[65] the probability of debris-generating collisions is increasing. While professional best practices, guidelines, and national regulations dictate the removal of space objects from outer space or at least from the most useful operational volumes, the timeframes within which this must occur is long, and the removal is not necessarily final. Even when the operator complies with the strictest guidelines, uncontrolled spacecraft pose significant dangers.

Satellites in low Earth orbit can be removed from space by lowering them into the atmosphere. Depending on the altitude of the operational orbit, this can happen without any propulsive manoeuvre, since atmospheric drag can exert enough force on the space object to complete the decay of the orbit within a set timeframe. This timeframe is set in international guidelines. For satellites orbiting higher, a propulsive manoeuvre is required to lower the orbit, so that natural forces can complete the removal. The time required for the orbit's decay depends on the manoeuvre.

Assume a satellite on a circular low Earth orbit at 1,000 km altitude. The time of its removal depends on the braking manoeuvre, when the originally circular orbit gets distorted to an elliptical orbit with periapsis[66] low enough for the atmospheric drag to have an effect. With enough fuel for the braking manoeuvre, the apoapsis can be lowered deep into the atmosphere or even to a negative altitude (collision course with the surface), so the ellipsis can be considered as a transfer orbit to destruction. This is the best possible manoeuvre, because the trajectory can be predicted accurately right to the descent into the dense atmosphere, and the manoeuvre can be timed to avoid any collision risk with space objects. However, this manoeuvre is energy-intensive (requires the most fuel), and the steep descent into the atmosphere can result in debris reaching the surface.[67]

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[65] The fate of the satellites in the geostationary orbit region is often misunderstood. It is true that the operators are obliged to remove the satellites at the end of their operational life from the geostationary altitude to a so-called "graveyard orbit." The exact altitude of this orbit depends on the physical properties of the satellite; however, it is generally 300 km above the geostationary altitude. The graveyard transfer manoeuvre removes the unmanoeuvrable satellite from the vicinity of the operational satellites, but this is not a final solution and does not remove the responsibility and liability of the spacecraft operator and the launching state.

[66] Periapsis is a generic term for the point of an orbit closest to the central body. In the case of an Earth orbit, "perigeum," often abbreviated as perigee, is also used. The farthest point is called apoapsis, or in the case of an Earth orbit, the "apogeum" or apogee.

[67] Most of the spacecraft structure is destroyed during aerobraking in the upper atmosphere. The steeper the reentry trajectory (the lower the perigeum), the shorter the time spent with aerobraking. While the peak temperature is higher during a steep reentry, the time available for the destruction of massive components is shorter. During a shallow re-entry (higher perigeum), more time is available for the destruction.

Less fuel expenditure results in an elliptical orbit where the periapsis is high enough so the satellite can survive the pass through periapsis and complete more orbits. Such a braking manoeuvre causes the satellite to slow down during the periapsis pass, and this slowdown lowers the apoapsis. The following periapsis pass will cause even more energy loss to lower the apoapsis again; ultimately, the orbit decays into the lower region of the low Earth orbit, and the satellite gets destroyed. During this elliptical orbiting, which can take years, the satellite periodically passes through the volumes most often used by productive satellites and crewed spacecraft. Every descent towards the periapsis and every ascent towards the apoapsis is a collision risk, and the orbit is constantly changing. During the time required for the decay, density of the upper atmosphere also changes (depending on solar activity), which further complicates the predictions. The advantage of a higher periapsis reentry is a shallower reentry angle, which means a more limited peak heating but a longer time spent in the upper atmosphere during the aerobraking, enabling a more complete destruction of the massive spacecraft structures.

Since the satellite slowly orbiting towards its destruction is not controllable or manoeuvrable, any collision avoidance manoeuvre must be completed by the other spacecraft. This means expending manoeuvring fuel otherwise budgeted for orbit maintenance, disruption of nominal operations, and potential loss of revenue as a consequence of both. While it can be argued that collision avoidance is a professional necessity during satellite operations, it is still a fact that disposals with unnecessarily long orbit decays place a burden on the operators of the spacecraft the satellite can collide with. A longer disposal manoeuvre (i.e. more orbits) raises the number of potential collision events with satellites in lower orbits. This time depends on the trajectory chosen by the operator of the satellite to be disposed of or by the disposal service provider.

A continuation of this case occurs when the elliptical orbits and periodical slowdowns themselves put the satellite to be disposed of onto a collision course with an unmanoeuvrable active (productive) satellite. In this case, the operator of the satellite to be disposed of complies with the regulatory requirement or professional duty to remove the inoperative spacecraft from orbit – but he also causes damage to another operator. Without the disposal manoeuvre, the collision would never have occurred. The collision would also not have occurred with a direct destructive reentry, but this would have put a financial burden on the operator of the inactive satellite that is not mandated by the current regulations.

These cases can be extended towards the general pollution of the outer space environment. With there being more and more abandoned unmanoeuvrable space objects and debris, some of them having predictable but practically "forever" orbits (medium Earth and geostationary/geosynchronous orbits), and some of them being on slowly decaying and constantly changing orbits, it can be argued that launching a satellite without collision avoidance capability is a mistake in itself. Moreover, any risk of a subsequent collision must be taken up by the launching party of the newer satellites, since they are launching into a known deteriorated environment. This approach is ethically questionable, since it removes the burden from the shoulders of those who caused the deterioration of the space environment to start with. At the same time, this could be the basis of a completely new approach to space utilisation that would prevent even more problems in the farther future. This would also significantly slow down the current growth of the space economy, but with the emergence of propulsion systems for the smallest of satellites and the aforementioned space debris removal services, the technology is available for this approach. It should also be noted that with the proliferation of space situational awareness sensors and service providers, it could be possible to keep track of and account for the debris generated by subsequent collisions to enable the use of third-party damage provision in the space treaties; however, this might become impractical as the original launchers are further and further removed from being capable of doing anything to prevent future collisions.

There is also an emerging trend of space operations that can only be classified as reckless, but the Outer Space Treaty again does not contain provisions about this. A good example is a Chinese proposal to launch a satellite into the geostationary altitude, but with an inclination of 180 degrees, that is, right in the opposite direction of the orbits of every other satellite there.[68] Since the purpose of such a satellite would be space situational awareness data collection, it can safely be assumed that the satellite would carry advanced sensors that can provide enough warning for collision avoidance during the satellite's operational lifetime.[69] However, the usual problem arises again: After the end of the operational lifetime, when the sensors and propulsion systems are shut down, this retrograde orbiting spacecraft body would pose a collision hazard to others every 12 hours, and the relative velocity of a collision would be significantly higher than that of any collision anticipated in the geostationary altitude before.[70]

4.4. Section Summary

Outer space is an essential resource for our current and future life. It is vast, but still finite, and parts of it can be considered choke points that are very vulnerable. Every piece of mass launched to orbit is valuable one way or another, but this value is not constant during the time spent in space. The Outer Space Treaty and Liability Convention describe how spacecraft operators and launching states are responsible for safe space activities, but these are very challenging to apply in real life.

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[68] This orbit is often called "retro-geostationary," but this term is, while descriptive, technically incorrect.

[69] He, Ma and Li, 2021.

[70] Since objects in the geostationary/geosynchronous altitude all orbit with approximately the same velocity and the inclinations are also usually very close, the relative velocity during a collision would be much lower than what we see in the low Earth orbit space; therefore, the kinetic energy of the collision is also much lower.

There is no universally accepted and trusted space situational awareness service that could be used as evidence in legal disputes. The Iridium 33 collision showed that such services' usefulness is questionable even for practical operations because of the inaccuracies (and the data downgrade to protect the otherwise classified real capabilities).

In this environment, satellite operators are practically flying blind, both physically and legally. As we have seen, there are situations in which noncompliance poses less of a short-term risk than actual compliance with guidelines and regulations. Since the current legal regime allows very relaxed compliance, those who decide to act responsibly (and not just comply with the words of the regulations) lose their position in the race because of the cost of the systems required. Extra propulsion and fuel reserve to enable a direct destruction transfer orbit, subscription to a more precise space situational awareness service or development of own sensors, and similar technological addons are not required by law and are expensive. Moreover, in the most valuable orbital region, these guidelines and regulations do not even mandate the final removal of space objects, leading to what is called the "graveyard orbit," which practically involves just dumping cadavers onto the roadside.

To develop sustainable space operation frameworks, the burden of cleaning up the orbits and keeping them free from long-term clutter must be distributed among the users. This means creating regulations that prevent risky operations in the future and ensure the removal of existing risks. The main ethical problem is that the current risks were created during activities that were compliant with the regulations and guidelines existing at that time. Stricter regulations do not remove the objects currently present in space, which will remain there for a time much longer than what our society can handle currently.

This problem is comparable to the long-term storage of nuclear materials, but is more acute. We see several predictions of potential collisions every day, and the debris resulting from these collisions (if and when they occur) will not remove the risk but, on the contrary, increase it.

It is necessary for the international legal community to develop a completely new and universally binding set of regulations that control the access to and use of outer space, enabling equal access and, at the same time, providing for safe and sustainable use, ultimately leading to an operational structure that prevents the abandonment of space objects. This will make space activities significantly more expensive. These regulations will not handle all the risks (malfunctions will still occur) but will be a significant step forwards from the current position, where a sudden catastrophe can endanger a large portion of space assets that are not prepared to handle this. It is also necessary to develop a financial structure to support the removal of the already existing space objects that are considered beyond their useful life.

Satellites are critical national infrastructure and military mission vital infrastructure; therefore, sustainable space operations are also important for national security. The current unsafe business practices endanger these space systems as well and can even pose an exploitable risk.[71]

5. Multiple-Use (Weaponisable) Space Systems

Just as it is very difficult to define where outer space is, it is also difficult to define what a space system can be used for. In addition to the usually understood "dual-use" – such as the use of space-based remote sensing or satellite communications to support commercial, government, and military operations from the same platform – new technologies enable more direct military applications. These technologies have peaceful or legitimate self-defence purposes but can be weaponised as destructive systems against spacecraft. The unregulated development of these technologies can create a race among space users to develop defensive technologies to counter them, and the testing and employment of the destructive systems will contribute to the degradation of the space environment described in Section 4.

A common property of these weaponisable systems is that they can be developed completely in the open, but their actual destructive properties can still stay hidden up to the moment of deployment against a spacecraft. This leads to destabilisation of the cooperative professional environment of outer space researchers, developers, and entrepreneurs. Moreover, they can lead to information and diplomatic operations against peaceful technology developers but can also be used as a perfect cover for weapons development.

5.1. Weaponisation of Orbital Debris Removal and On-Orbit Maintenance

On-orbit maintenance is a proven technology to extend the life of space hardware that otherwise would become an uncontrolled drifting hulk. It is beneficial from the economical point from view as well, because the production and launch of spacecraft that provides the orbital life extension is cheaper than that of a completely new productive satellite. Large telecommunications satellites typically reach their end of useful life because of the depletion of stationkeeping fuel or the degradation of power generation and storage systems. Currently, it is possible to provide stationkeeping to satellites that were built without any onboard system to enable this, as long as the orbital life extension spacecraft can grab a suitable structural part.[72] The

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[71] For a descriptive narration on this topic, see: the Chapter 1 of *Visions of Warfare 2036*, published by NATO Allied Command Transformation; Phillips and Cole, 2016, pp. 13–18.

[72] Spacelogistics, 2021.

inclusion of specific attachment points, navigation aids,[73] and power connectors will make these operations easier and also enable the augmentation of the power system. Modular satellite architectures will enable even replacement of the payload, thereby further extending the useful life of the originally launched bus. Altogether, on-orbit maintenance will reduce the number of space launches necessary to provide essential space services as well as reduce the number of abandoned spacecraft, especially in the geostationary belt, which is in my opinion the most vulnerable orbital region.

It can be assumed that on-orbit maintenance will be performed as a cooperative action between the two spacecraft, and the target satellite will have at least limited attitude control. Even in this case, the approaching spacecraft need to have significant manoeuvrability. However, in the case of orbital debris removal, where the target space object is completely out of control, the approaching spacecraft needs even more agility and aggressive grappling tools. That is, because the target space object is out of control, the approaching spacecraft must be able to overcome its movements in all dimensions and degrees of freedom of movement to stabilise it and then move it to the disposal orbit.

It takes very little imagination to extend this scenario to when the target is a perfectly controlled productive satellite and the approaching spacecraft removes it against the will of the operator, attaches a device to it, or damages the satellite. All technologies required to do this (sensors, calculation of relative movements and interception geometry, orientation and translation manoeuvring, physical attachment, and manipulation tools) can be developed under the veil of developing a commercial or public service solution. At the same time, any commercial or public service solution development can be called offensive technology.

Co-orbital antisatellite operations, which this on-orbit maintenance or debris removal technology can enable, do not necessarily result in debris clouds and, therefore, are significantly more dangerous than the direct ascent antisatellite weapons (that always generate debris). Debris clouds resulting from kinetic collision of the direct ascent weapons have long-lasting effects on the space environment and can threaten the satellites of the aggressor. This can discourage the aggressor from using them. A co-orbital attack can achieve the same result without the release of debris, or with just a limited amount of it. However, note that when the goal of the aggressor is debris generation, co-orbital operations are capable of that also.

It must be noted that these systems have another vulnerability, which is independent of the intentions of their developers and operators. The cybersecurity of these on-orbit maintenance or debris removal spacecraft and their control systems must be extremely strong, considering their intended role. Without this, an adversary with access to the control systems can take over the spacecraft after launch and use it for their purposes, either preventing the intended mission or using it for an attack. These cyberattacks can be disguised as malfunctions, putting the blame

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[73] For information about navigational aids for proximity operations and grappling, see: Admatis, no date.

on the original operator. To flip this scenario, hostile deployment of a debris removal spacecraft can be presented as a consequence of a cyberattack by a third party. In this case, the hostile operator portrays itself as a victim, assuming the damage to their reputation but disguising their hostile intent.

5.2. Development of Direct Ascent Antisatellite Systems Under the Guise of Ballistic Missile Defence

Although direct ascent antisatellite weapons are not as flexible as co-orbital ones and their employment has far-reaching consequences, they still can have a place in the counterspace portfolio of a nation. They can support strong strategic messaging, and their information operation effect is also considerable.

Up to now, four dedicated kinetic kill antisatellite weapons[74] tests and one deliberate destruction have been executed:

- Shootdown of Solwind P78-1 by the US[75]
- Shootdown of FY-1C in 2007 by China[76]
- Operation Burnt Frost in 2008 (shootdown of USA-193 by the US), which was not announced as a test but as an emergency action to prevent remains of the satellite from reaching the surface after an uncontrolled reentry[77]
- Mission Shakti (shootdown of dedicated target satellite Microsat-R by India)[78]
- Shootdown of Kosmos 1408 in 2021 by Russia[79]

After the 2007 antisatellite weapons test by China and a similar test by Russia in 2021, the international community condemned such actions very strongly. The 2008 US action (Operation Burnt Frost) and the 2019 Indian test did not generate such strong reactions. One reason was that these collisions happened at a much lower altitude, and therefore much of the debris clouds re-entered within months; during the decay, the debris trajectories usually did not intersect with the orbits of productive satellites at higher altitudes.[80]

Of these tests and the USA-193 interception, only the ASM-135 missile used by the US in 1985 was a dedicated antisatellite weapon. The interceptor used by China in 2007 might also have been a dedicated antisatellite weapon that was later repurposed to a ballistic missile defence role, or vice versa. The SM-3 (US, 2008), Prithvi

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[74] Earlier antisatellite weapons carried nuclear warheads, and the test success criteria were that the warhead passed close enough to the target (so the target was present in the effective kill volume of the warhead). These tests did not generate debris. Kinetic kill weapons do not carry explosive or nuclear warheads, and they directly collide with the target and always generate debris.

[75] Swopes, 2017.

[76] Weeden, 2007.

[77] Kelso, 2008.

[78] Oltrogge, Kelso and Hall, no date.

[79] Weeden, 2022.

[80] A small percentage of debris got ejected onto higher orbits, but this was significantly less than the debris generated by the Chinese or Russian tests.

Mk II (India, 2019), and A-235 Nudol missiles all were originally ballistic missile defence weapons repurposed for an antisatellite role.

Ballistic missile defence is a very important capability for a nation to safeguard their citizens and allies, especially with the accelerated proliferation of intermediate-range ballistic missiles and hypersonic warhead delivery vehicles. It is an undisputable right of any nation to work on these defences. However, the capability requirements of midcourse interceptors and direct ascent kinetic antisatellite weapons are practically similar. The detection and targeting procedures are even simpler in the case of the antisatellite role (the time window is more relaxed in this case). Moreover, while the testing of direct ascent kinetic antisatellite weapons is practically universally condemned because of the resulting debris, testing of ballistic missile defence applications happens on suborbital trajectories, and the debris reenters immediately. The suborbital trajectory still enables the kinetic testing of targeting, interception, and manoeuvring. The general flight dynamics of the interceptor can be tested against simulated targets. This way, the antisatellite capability can be developed, tested, and validated without any actual debris-generating orbital interception.

Again, the dual usability of this technology opens the way to hide the development of systems that would destabilise and endanger the physical space environment and, at the same time, enable information operations and strategic messaging against legitimate defence-related development, thereby undermining cooperation in the professional community.

5.3. Multiple Usability of Electromagnetic Support and Defence Systems

The defence and national security use of Earth observation (usually called Intelligence, Surveillance and Reconnaissance [ISR]) is a very important supporting mission and can be a force multiplier in conflicts. Therefore counter-ISR is essential for ensuring operational security (OPSEC),[81] but at the same time, precise prediction of the overflight of adversary reconnaissance satellites[82] supports another information operation as well – military (or strategic) deception.[83]

To enable accurate overflight prediction (for concealment of real intentions or to show misleading information), the orbit of the overflying satellite needs to be known. The data for orbit determination can be obtained by active electromagnetic sensors, namely radars and laser ranging systems. These systems illuminate the satellite and measure the relative movement parameters by analysing the reflected signal. The orbit can be calculated from a series of measurements. Some satellites carry

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[81] OPSEC is the procedure for keeping essential elements of friendly information from the adversary, thereby keeping secret the intentions and activities of the force.

[82] In NATO terminology, this is called satellite reconnaissance advance notification.

[83] Military deception involves replacing the real essential elements of friendly information (kept secure by OPSEC) with fabricated ones and enabling the adversary to learn of these so as to shape the activities of the adversary into a desired direction.

retroreflectors to increase the reflected energy, but generally such measurements do not require cooperation of the target space object.

When it comes to the point in a conflict where active denial of information collection becomes a necessity, sensors on the overflying satellite can be influenced or overwhelmed by illumination with electromagnetic energy. Against radar satellites, this action is usually called jamming and is done by radio frequency emitters in the electromagnetic spectrum segment used by the radar.[84] Against optical satellites,[85] this action is called dazzling,[86] and it is done by laser emitters tuned to the wavelength(s) used by the camera of the satellite.[87] Jamming or dazzling does not damage the sensor, only obscures the image (or the reflected radar spectrum), making it unusable as a primary source of intelligence (at the same time, jamming or dazzling is an indirect indication of a high-value target).[88]

Although remote sensing of a sovereign state from outer space is generally considered legal, active denial of information collection in times of tensions, crises, or conflicts is also an understandable action. Since jammers and dazzlers do not cause permanent degradation of the spacecraft, it can be argued that the satellite is not damaged, even though a commercial operator can lose money by being unable to fulfil a contract.

However, the probability of permanent damage only depends on the energy absorbed by the sensor (or, in extreme cases, the satellite body). In this case, the illuminator becomes a directed energy weapon that can either take out the sensor (typically the optical sensor, but radar receivers can also suffer damage from high-power microwave irradiation) or damage other spacecraft systems. It must be noted that the damage threshold depends on the physical properties of the sensor, relative geometry of the sensor and illuminator, distance, and weather (transparency of the atmosphere); therefore, the damage can occur without the intention of the perpetrator. However, damage to other spacecraft systems is unlikely to occur this way, as these systems are more robust.

The problems with these electromagnetic energy systems are similar to those mentioned above. The outcome of the illumination depends solely on the energy output. All tracking and targeting systems are the same for different applications. Therefore, it is possible to fully develop and test the system under the veil of a space situation awareness sensor and complete the high-energy testing under laboratory

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[84] One example of satellite (and also airborne) radar sensor jammers is the Russian Krashuka 4. For more information, see: Army Recognition Group, 2024.

[85] In military terminology, such optical payloads are usually called electro-optical, abbreviated as EO. On the one hand, this is unnecessary since no ISR satellite uses wet-film cameras nowadays; on the other hand, this can lead to misunderstandings since Earth observation is also abbreviated as EO. Therefore, the use of electro-optical is not recommended.

[86] SPARTA, 2023.

[87] One example of satellite optical sensor jammers is the Russian Peresvet. For more information, see: *"Peresvet" combat laser complex*, no date.

[88] For a controlled demonstration of the effects of laser dazzling, see: Schleijpen, 2008.

conditions. Moreover, with the previously mentioned laser broom space debris removal technology, it is possible to do high-energy testing in the open. Everything written above about other multiple-use technologies concerning the destabilising effects and the potential information and diplomatic operations are true here also.

5.4. Section Summary

This section described several technologies that, on the one hand, can be very beneficial for safe and sustainable space operations but, on the other hand, are easily weaponised to be used for destructive offensive capabilities. A common point in these systems is that practically all the development and testing can be done under the guise of peaceful or at least defensive military technologies; meanwhile, the weaponisation is clearly understood by all concerned parties. This gives way to information operations and strategic messaging that distort and destabilise the otherwise useful development efforts and potentially undermine international cooperation.

Altogether, the proliferation of on-orbit maintenance, space debris removal, and space situational awareness sensor technologies (with their peaceful applications) would support sustainable space operations and could turn the tide of the currently deteriorating physical space environment. Meanwhile, ballistic missile defence interceptors, deployed in limited numbers, would discourage rogue states from offensive missile weapons development, while not breaking the existing equilibrium between larger nuclear powers.

It is desired that the international legal community develop safeguards, controls, regulations, and guidelines for the safe, secure, and transparent development of these technologies. It is necessary to prevent an arms race in counterspace capabilities, as well as prevent the degradation of the international political-diplomatic environment, which could be one outcome of uncontrolled development. These regulations need to be universal to prevent the reoccurrence of tensions that accompanied (for example) the termination of the Intermediate-Range Nuclear Forces Treaty.[89]

6. Summary

Outer space is a very dynamic environment. This statement is true for physics, business, and also the legal environment. International and national legislation is, on

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[89] The Intermediate-Range Nuclear Forces Treaty was a bilateral treaty between the US and Soviet Union/Russia to prevent an arms race in the field of nuclear weapons, against which the existing deterrent capabilities would have been inadequate. Unfortunately, the treaty did not follow the changes in the strategic environment, was used to undermine the preexisting understanding between the parties, and was ultimately terminated.

the surface, very active. However, fundamentals of the outer space legal regime are still based on the Outer Space Treaty and the related agreements and conventions, which were drafted in a very different era. The technology, politics, and economics of current space activities are far removed from those on which the Outer Space Treaty is based. The fact that the Five Treaties (Outer Space Treaty, Rescue Agreement, Liability Convention, Registration Convention and Moon Treaty) were successful in governing space activities for such a long time is not evidence of their versatility. It is just plain luck, which is supported by the diligence and professionalism of the actual space operators. Most of the provisions in the Five Treaties were never tested. No astronaut required rescue, only once did a state have to assume liability for any damage caused by a space launch, and a significant percentage of spacecraft were never registered. However, since nothing can be done about this, really nothing is actually done about it.

With the proliferation of space operations, increasing number of commercial space actors, and new technologies enabling new operational architectures and business opportunities, the time when the Five Treaties will be put to the test is nearing. It is my fear that they will fall short.

These treaties were signed during the Cold War, when the international relations related to space were much more cooperative than nowadays. Now, the space environment is described as "congested, contested, and competitive" or outright "disrupted, degraded, and denied." The multifaceted space environment is practically detached from the Five Treaties that should regulate it. We are at the end of the grace period during which this detachment still does not have practical consequences, but with the increasingly complicated space activities, a new set of regulations is necessary.

These new regulations need to address the shortcomings of the existing treaty system that are being exposed by the advancement of the technology and business. This chapter listed just a few examples of these shortcomings.

It is now absolutely necessary to, after roughly 80 years of space activities,[90] define where exactly is outer space. This definition will enable internationally recognised and binding regulations (comparable to those that exist now for airspace and the seas) for the physical domains concerned, namely the volumes above the airspace generally used for air operations. It will be necessary to define more than one volume to account for the physics of the upper atmosphere.

After the definition and delimitation of outer space, the question of zoning of outer space needs to be addressed. The current "free for innocent passage" approach is inadequate. It does not provide for operational safety, and especially not security. While the prohibition of claims of state sovereignty should be maintained, a regulated zoning around operational spacecraft is necessary. It is important for this protective zoning to be tied to the existence of the spacecraft itself, and not to the

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[90] The first vehicles reaching the volume usually considered as outer space were various test launches of the German V-2 (A-4) rockets, launched between 1942 and 1946 by Germany and the US.

owner, operator, or the party that files for the registration of the spacecraft. After this zoning, rules for the protection and defence of these zones can be defined.

No less important is the delimitation of operational spacecraft (that need to be protected) from objects that reach the end of their useful life (and that need to be removed safely to enable sustainable space operations for the generations to come). Just as the pollution of the space environment is a human action, this "cleanup" and maintenance need to be human actions also. Random forces of nature cannot be trusted with this job anymore.

Ultimately, the legitimate commercial and defence technology developments need to be delimited from weapons applications. War is part of our culture, and space is an effective supporter of the war efforts on the surface. Therefore, it is unavoidable that war will reach outer space. However, the current grey zone, in which warfighting technology is developed, is undermining the security of outer space even in peacetime; at the same time, it hinders peaceful and commercial research and development. Just as there are rules for military activities on Earth, such rules are (sadly, but unavoidably) necessary for outer space too. This task is made overly difficult by hybrid conflicts, where capabilities other than traditional military might are used.

Creation of these rules will require an international undertaking never seen before, involving states, international and supranational organisations, businesses, and academia. Since this program will most likely take decades, there is no reason for delaying the start any longer.

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