TECHNICAL AND LEGAL PROBLEMS OF SPACE DRONES

Małgorzata Polkowska
War Studies University, Warsaw, Poland
Correspondence: m.polkowska@akademia.mil.pl

Abstract

The article presents several legal and technical challenges related to space drones. This topic is ground-breaking, as space law (without a definition of space object or space drone) is attempting to keep up with the evolving space technology.

The design and construction of space drones may be used to study Mars, Venus and other celestial bodies. These first two planets were studied well in the 20th century; for example, the atmosphere of Venus was explored by two balloons. A few years ago, the concept of using UAVs in space missions appeared. On April 19, 2022, a successful experiment was carried out with the first small Mars space drone *Ingenuity*; it took ten photos (of the crashed lander), which were sent to the *Perseverance* rover, and through it to the Earth. Larger space drones are currently being developed; one of the projects concerns a platform for launching spacecraft from a height of 18 km above the Earth, and another assumes the use of nuclear propulsion in space drones.

However, it appears that the law is unable to keep up with evolving space technology. Plans for the use of space drones may face many difficulties due to the imprecision or loopholes of international space law and the need to rely on *soft* law, i.e. regulations and recommendations whose adoption depends on the goodwill of states. Besides, using analogy to unmanned aerial vehicle regulation (EU, ICAO) may not prove to be always possible. What is more, there is a scarcity of literature and lack of legislation on space drones, which is a challenge for international lawyers. Aviation law and aviation organizations taking care of UAVs are good examples to be followed by space legislators.

Keywords: unmanned aerial vehicle, space drones, space law, atomic energy

1. Introduction

The process of space development is not possible without appropriate research. Therefore, a number of states, mainly the United States, have earmarked significant funds for this purpose. The traditional approach to studying celestial bodies is to send manned ships into space; however, this entails serious health problems and even death for its members. In expeditions organized by NASA (National

DOI: 10.5604/01.3001.0016.3294
Received: 13.02.2023 Revised: 11.03.2023 Accepted: 15.03.2023

Aeronautics and Space Administration), 17 astronauts have lost their lives, including disasters of the space shuttles *Challenger* in 1986 (crew of 7) (https://nauka.tvp.pl/58264848/wahadlowiec-w-ogniu-mija-20-lat-od-katastrofy-promu-columbia) and Columbia in 2003 (also 7 astronauts). Similar disasters have taken place in other countries, including in the USSR (Russian Federation). In this situation, engineers drew attention to the need of developing technologies intended to enhance the safety of astronauts and reduce the high costs of space missions. For this purpose, robotics is being developed (e.g. in the US and Canada) and additionally in recent years work has been intensified to create of space drones (cheaper and more efficient than the previously produced space devices).

So far, only one small space drone has been built and tested, but there are plans for larger and more advanced ones. Replacing traditional propulsion with nuclear power is also being considered. Therefore, when designing such devices, a number of factors and limitations should be taken into account, such as, for example, maximum dimensions, total weight, cost, protection of the space environment, temperature, communication, on-board data handling and especially propulsion. The legal requirements and definitions of space drones in international space law should follow.

All those issues are discussed in the article, which comprises an introduction and four main chapters. Chapter 1 includes an introduction, while chapter 2 presents some examples of EU and ICAO provisions referring to UAVs. Chapter 3 contains an analysis of international space law, partly not adapted to the present challenges in space development, and provides some new legal initiatives on space legislation. Chapter 4 presents projects for the construction of various space drones. The presented facts indicate that nuclear propulsion is not the only alternative to space drones. Finally, Chapter 5 deals with existing regulations and recommendations on the use of nuclear energy to propel ships and space devices (they may also apply to space drones). The last chapter of the article concludes all author's observations.

2. Unmanned Aerial Vehicle – a model for space drones

2.1. Unmanned aerial vehicles

An *unmanned aerial vehicle* (UAV) is commonly known as a vessel with no pilot, crew or passengers on board. The drone, which additionally has a ground controller and a communication system, is called UAS (*an unmanned aerial system*). Such vessels can be remotely controlled by humans, or have varying degrees of autonomy, from assisted autopilot to completely autonomous operation. UAVs, which were created in the 20th century, were intended to perform some difficult military missions, and in the 21st century, UAS have become basic devices in most armed forces. With the improvement of control technology and the decrease in costs, their use then expanded to several non-military applications, including monitoring forests, farmland and infrastructure (including airports), tracking severe storms, and serving as telecommunication relay platforms for aerial photography and cargo transportation (Franke, 2015). Most UAVs are operating in the US – most of them are devices used by amateurs. Professional UAVs have been part of the NASA fleet for over 40 years. These are devices powered by solar energy or using electric motors (FAA, 2022).

2.2. Legal requirements

The issue of unmanned aerial vehicles was first taken up during the 1944 Chicago Convention on International Civil Aviation. Over the following years, the International Civil Aviation Organization (ICAO) tried unsuccessfully to go beyond Article 8 of the Convention and bring them under international control (Pazmińo, 2021). On the other hand, the European Union adopted a regulation on unmanned aerial vehicles, which entered into force on 31 December 2020 and was to be applicable in all EU countries EU (Regulation UE 2019/947). Another order of the European Commission of the EU of April 22, 2021, clarified the rules for applying these provisions (Regulation UE 2021/664). A regulatory framework for the U-space was provided. U-space is defined as a set of new services relying on a high level of digitalization and automation of functions and specific procedures, designed to provide safe, efficient and secure access to airspace for a number of unmanned aircraft. According to these regulations, operations of unmanned aerial vehicles have been classified on the basis of their degree of risk. Three categories of operations have been distinguished: open (operation with the lowest risk), special (operation with medium risk) and certified (operation with a level of risk comparable to manned aviation). In accordance with the requirements of the open category anyone who wants to fly an unmanned aircraft weighing more than 250 grams or furnished with a camera, will be obliged to register the device with the appropriate national office, undergo training and testing. Operations in the open category may only be performed within the sight of a pilot or observer, up to a maximum height of 120 meters. It is also required to respect the privacy of others and keep a safe distance between an unmanned aircraft and other people, animals and aircraft (Regulation EU 2021/664).

In the United States, since 2015, a requirement has been imposed that an unmanned aircraft that will be used for recreational purposes weighing more than 250 grams – up to 25 kg must be registered with relevant authorities. Unmanned aircraft weighing up to 250 grams do not need to be registered. The registration fee is $5 and is valid for 3 years. With the completion of the unmanned aircraft registration process in the US, the petitioner receives a certificate. The last step to fully legal piloting of an unmanned aircraft in the US is to take a test (very easy) called The Recreational UAS Safety Test (TRUST) – it is free and can be done online on several websites (FAA, 2022). Similar regulations have been introduced in other countries.

There are almost 200 000 UAV users in Poland, which is why the *Civil Aviation Authority* and the *Polish Air Navigation Services Agency* (PANSA), as the first in Europe, has launched the PANSA UTM operational UAV flight coordination system. It allows inter alia fast, digital, non-verbal communication between air traffic controllers and UAV operators. Thanks to it, UAV operators can quickly verify flight opportunities in a given area, digitally submit a flight plan and obtain permission to fly in a situation where it does not pose a threat to the safety of aircraft. According to the estimates of the Polish Economic Institute, the value of the UAV market in Poland will amount to PLN 3.26 billion by 2026, but the effect on the entire economy may increase to PLN 576 billion (https://www.gov.pl/web/infrastruktura/miej-drony-pod-kontrola--od-31-grudnia-nowe-zasady-lotow-dronami-w-calej-europie).

2.3. ICAO regulations

ICAO became very active in the area of UAVs. The first ICAO circular on UAVs (*International Civil Aviation Organization*) was devised in 2011. Its authors stated that civil aviation has so far been based on the concept of a pilot operating the aircraft from inside the aircraft itself and most often with passengers on board. Removing the pilot from the aircraft involves important technical issues, while the deployment of unmanned aerial systems in the single sky will be a long-term activity in which many problems must be solved, including licensing and qualification, collision detection and avoidance technologies, protection against unintended or unlawful interference, separation standards from other aircraft, etc. The goal of ICAO for unmanned aviation was to provide a basic international regulatory framework through S*tandards and Recommended Practices* (SARP) together with supporting *Procedures for Air Navigation Services* (PANS) to support the routine operation of UAVs around the world in a safe manner, harmonized and smooth, comparable to manned operations. ICAO predicted that UAVs information and data would evolve rapidly as the aerospace industry develops (https://www.icao.int/meetings/uas/documents/circular 328 ICAO).

Subsequently, Member States requested ICAO develop a regulatory framework for unmanned aerial devices. In this situation, this organization reviewed the existing national legislation pertaining to unmanned aerial vehicles to identify common features and best practices that would be consistent with the ICAO aviation framework and that could be implemented by Member States. The result of this activity are the ICAO Model UAS Regulations (issued in 2022) and the accompanying Advisory Circulars (AC). These documents offer Member States a template to implement or supplement their existing UAV regulations. At the same time, ICAO encourages States that have implemented UAV regulations to share their regulations. These regulations will then be added to the “Current State Regulations” repository available on the ICAO website: UASToolkit. As the States improve or expand their UAV regulations, they are invited to notify ICAO and send copies of their amendments to the organization.

The model ICAO regulations recommend the introduction of, among others, the following rules:

– all unmanned aerial vehicles (UAS) should be registered;
– unmanned aerial devices weighing 25 kg or less and operating under standard operating conditions do not require additional operational inspection; however, if their weight exceeds 15 kg, they require inspection and approval;
– NAA (an organization established by ICAO to implement the regulations into the legal order of the Member States) promotes the creation of national organizations for licensing remote controls, issuing certificates, etc;
– in addition, document AC 102-37 was issued to define guidelines for the transport of dangerous goods by UAVs (https: //www.icao.int>safety/pages).

3. International space law and the status of space objects

3.1. Outer Space Treaty

In 1963, at the request of UNCOPUOS (*United Nations Committee on the Peaceful Uses of Outer Space*), the UN General Assembly adopted a declaration of legal principles governing the activities of states in the field of exploration and use of outer space. None of the five space treaties were amended until today. In 1966, a treaty regulating outer space was recommended and approved on January 27, 1967 (Jakhu, 2007).

Article I sentence 2 of the *Outer Space Treaty* (OST) provides for the freedom of outer space. It confirms that outer space, including the Moon and other celestial bodies, is not subject to any type of appropriation and emphasizes that its exploration and use should serve the good of the entire humanity (Common Heritage of Mankind – CHM). Outer space, including the Moon and other celestial bodies, is free for exploration and use by all states, without any discrimination, on an equal basis, and in accordance with international law. This freedom applies to both legal persons and international organizations. The Moon and other celestial bodies were considered to be nobody's property (Latin: *res nullus*) or common land (Latin: *Terra communis*). The Outer Space Treaty does not define the exact boundary between airspace and outer space but lays down the foundations of international space law. This treaty is part of international law and respects its principles (Tate, 2006). There is no definition of space object in international space law, so there is no certainty whether space drones may be called UAVs and which regulations should be used in outer space for them.

Article II of the OST deals with the principle of non-appropriation of Outer Space. Outer space, including the Moon and other celestial bodies, is not subject to national appropriation, whether by the declaration of sovereignty, by use or occupation, or by any other means. It is also worth adding that the principle of the non-appropriation of Outer Space is included in the customary norms of international law (international custom) of all mankind. International custom is a specific source of international law. The fact that an international custom is universal (not local) means that it binds all members of the international community (O'Brien, 2021).

3.2. Rescue Agreement

In 1968, an agreement was adopted on the rescue of astronauts, the return of astronauts and the return of objects launched into space. This act establishes procedures to be followed in situations where the crew of a spacecraft has an accident or makes a forced or unintentional landing in its territory or any other place outside the jurisdiction of any state or ditches on the High Seas (Polish Journal of Laws/Dz.U. from 1969 No. 15, item 110).

3.3. Liability Convention

The achievements of international space law were extended in 1972 by the Convention on liability for damage caused by space objects (similar to the provisions of private Aviation law). Although the Convention contains numerous shortcomings, it can be said that it is a step forward compared to Art. VI and VII of OST, and its creation is an important stage in the further development of legal regulations regarding space activities. However, the provisions of this convention lack clarity and precision. Like the OST, the 1972 convention does not contain any instructions as to the definition of the term space object. Also, joint and several liabilities defined in its Art. V are unclear. Regulations are ineffective, and government liability procedures fail to ensure a proper level of compensation for victims of space accidents. It does not provide a system of mandatory courts or any means by which a final and binding decision would be adopted; there is no guarantee that the complainant State would receive any compensation (Foster, 2007). The Convention on liability for damage caused by space activities is outdated due to the increasing globalization and privatization of the space industry. Hence the need to amend this act, modelled on the convention on liability in aviation and maritime law (Lee, 2006).

3.4 Registration Convention

In 1975, the Convention on the Registration of Objects Launched into Outer Space was adopted (Polish Journal of Laws/Dz.U. from 1979). According to its Art. II sec. 1, when a space object has been launched into or beyond Earth orbit, the launching State shall be required to register the space object by an entry into the appropriate registry which it to maintain. Each contributing State is obliged to notify the Secretary-General of the United Nations of the establishment of such a register. The Registration Convention did not specify when states must create a space registry, nor the time when information should be provided (before or after launch). Therefore, the states themselves decide when to notify the UN Secretary (Hobe, 2019).

In practice, many states fail to comply with the obligation to register on time or provide incomplete information required for registration, submit applications in various forms, or deliberately delay the adoption of the registration convention. For this reason, the number of unregistered objects increases, and consequently so does the number of collisions of objects. For example, in 2001, the US did not register 141 of its over 2 000 satellites. The Convention does not require the launching states to properly identify (mark) the spacecraft or its parts. Sometimes registration and liability issues arise, for example when a satellite is relocated to a non-excluding country. There is no certainty in international law as to its application to commercial activities (Oosterlink, 1995).

3.5. Moon Treaty

As has already been mentioned, in 1979 the Moon Treaty was adopted. According to Art. 1 sec. 1 of its provisions it was also to be applicable to other celestial bodies within the Solar System, excluding the Earth, unless special legal norms come into force with respect to any of these celestial bodies. All activities on the Moon, including its exploration and use, are to be conducted in accordance with international law, in particular, the Charter of the United Nations, and taking into account the declaration of principles of international law concerning friendly relations and cooperation between States in the interests of maintaining international peace and security (Article 2).

Article 3 provided that the Moon may be used by all state parties to the treaty only for peaceful purposes. It is forbidden to resort to any threat or use of force or act in a hostile way on the Moon. It is also prohibited to use the Moon to perform such an act or to make such a threat with respect to the Earth, the Moon, a spacecraft, its personnel, or man-made space objects. Section 3 comprises a ban on the placing by states in orbit around the Moon of any object with nuclear weapons or other weapons of mass destruction. It is also forbidden to establish any military bases, devices and fortifications on the Moon, as well as to conduct military manoeuvres (this provision is extremely important, as a large part of satellites is used for military purposes). Article 4 para. 1 of the Treaty on the Moon stipulates in particular that research and use of the Moon are the domain of all mankind and will be carried out for the benefit and in the interest of all countries, regardless of their degree of economic or scientific development. Many scholars note that the treaty is imperfect and most of its provisions redundant. It is alleged that it was poorly constructed (and therefore obtained a very small number of ratifications) (Hermida, 2004).

Other space treaties have also failed to gain widespread acceptance. Most countries have ratified the OST. However, successive treaties received less and less recognition. Therefore, it was postulated that the existing treaties be reviewed so that they meet with greater approval of the states (Reynolds, 2005). The principle of freedom of outer space is the main interpretative directive of provisions of, among others, the OST. Nevertheless, it is often criticized due to the non-precise wording of all five international space treaties (such as space objects) and due to their conservative nature not adapted to the growth of space technology (Leister, Frazier, 2000). For this reason the Aviation law and ICAO rules applicable to UAVs can serve here as an example of space law.

3.6. New legal initiatives

In the absence of international regulations regarding new space initiatives of private entities, some countries are developing their own internal legislation. In such a way the idea of global cooperation between states and private entities was born. However, there is still a lack of sufficient legal solutions to regulate, for example, the operation of satellites. Even when running space tourism, numerous procedures are needed, in particular those related to: transport, ship equipment, types of routes, crew and passenger insurance, emergency procedures, spaceport infrastructure, and the like (Farand, 2003).

Due to the fact that there is no definition of space object, NASA provided a kind of classification of *space drones*. In 2003 NASA identified eight broad classes of robotic spacecraft according to the missions of the spacecraft: 1. Flyby spacecraft, 2. Orbiter spacecraft, 3. Atmospheric spacecraft, 4. Lander spacecraft, 5. Rover spacecraft, 6. Penetrator spacecraft, 7. Observatory spacecraft, 8. Communications spacecraft. This classification of unmanned spacecraft still does not specify the term space drone. Probably in 2003 there were no projects of building such devices. Even today, this term does not apply in international space law. Meanwhile, space drones may be the most efficient and promising type of unmanned spacecraft. The foundations of international space law have never been changed since their adoption and do not respond to modern challenges regarding the development of space. Meanwhile, the basics of Aviation law are periodically reviewed and improved, in line with advances in aviation science and technology (Vyshnovetska, Melnyk, 2020).

4. Projects of building space drones – achievements and problems

4.1. UAVs for Space

The rapid increase in the number and types of unmanned aerial vehicles (UAVs) has resulted in the interest of some countries, organizations and private companies in the construction of space drones that could independently explore planets and other celestial bodies as of the beginning of the 21st century. UAV technology has great potential to support various space missions. In general, various techniques are available for observing space objects, such as telescopes, probes, flying spacecraft, orbiters, landers and rovers. However, the advantages of UAVs, as compared to other devices for studying celestial bodies, seem to be much better. UAVs have much better manoeuvrability and resolution of transmitted images compared to the previously used devices sent into space.

The interest of engineers trying to build a UAV for space tasks was aroused by *Mars*, which has a much lower air density compared to Earth. Initially, it was considered that methanol fuel would be the best means of powering a space drone; powering by a solar beam seemed even more reliable (Komputer Świat, 2022).

Some earlier projects involved the use of balloons in space. A balloon is a simple device that does not require power to maintain altitude. Overpressure balloons can travel for longer periods owing to the reduced gas leakage inside the balloon. A super-pressurized (inflated) balloon is considered a device that often maintains a positive internal pressure as compared to the atmosphere in which it floats. Such balloons are mainly intended for exploration above the surface of Venus (Odkrywcy planet, 2018).

4.2. Planets in the solar system

Venus is one of the four terrestrial planets in the solar system. In terms of size and mass, it is very similar to Earth, which is why it is often described as a sister of our plant. The diameter of Venus is only 650 km smaller than the one of Earth, and its mass equals to 81.5% of the mass of the Earth. However, conditions on the surface of Venus are fundamentally different from those on Earth, due to its thick atmosphere composed mainly of carbon dioxide. It makes up 96.5% of the mass of the atmosphere, while the remaining 3.5% is mostly nitrogen.

In 1985, two identical Soviet Vega probes (1 and 2) were launched. Both probes, in addition to traditional landers, were equipped with balloons floating in the atmosphere; they reached the planet's atmosphere on June 11 and 15, 1985 at an altitude of 54 km. The balloons (pressurized type) made in France, with a diameter of 3.54 m, were filled with helium. Each balloon weighed 21 kg. After the balloons became detached from the landers, measurements of atmospheric pressure, temperature, wind speed, and atmospheric density began. The balloons were supposed to work for 6 hours but their working time (thanks to lithium batteries) was extended to 46 hours. The balloons were tracked by 20 radio telescopes on Earth, 6 of them Russian; the remaining 14 radio telescopes were coordinated by the French space agency CNES, working with NASA. During the 4 days of the balloon flight, 1,200 data transmissions were received from them. With the help of the wind, they moved (e.g. Vega 2 with an average speed of 66 m/s) from the shadow side of the planet to the light side. There, the lithium batteries ran out and contact with the probes was lost (Martyniuk, 2022).

The slow rate of rotation of Venus causes a very long solar day. This means that the speed needed to keep the space drone at the subsolar point is low, at the equator it is only 13.4 km/h – so a system of solar-powered devices was proposed. The research results indicate that in some areas of the atmosphere of Venus, any type of flying vehicle and propulsion device can operate freely.

The main purpose of a vehicle sent to explore space is to properly survey the area, map a wide area of the planet and obtain relevant information. The various approaches previously used to explore planets were found to have many weaknesses. The landers are limited to the area surrounding the landing site and can only survey the adjacent area (up to 1 km), while the Mars UAV can potentially fly 500 km. Rovers have some advantages over stationary landers in that they cover a larger area, but they are more prone to accidents (colliding with a rock or falling off a cliff). Compared to landers and rovers, an orbiter can collect much more data, which helps obtaining more accurate information about the surveyed area. Orbiters are capable of spatially mapping wide areas, but their resolution is limited to a few meters. Moreover, they can be hit by meteorites or other debris. Unlike orbiters, space drones will be closer to the surface of the celestial body; therefore, they will be more secure and their information more accurate (Plaza, 2021).

4.3. Mission proposals

In February 2017, the Johns Hopkins University Applied Physics Laboratory and NASA proposed a research mission to Saturn's moon Titan using a drone called *Dragonfly*. The device will have an eight-bladed rotor configuration with vertical take-off and landing capabilities and can explore both the crust and the atmosphere. However, the *Dragonfly* will have to survive Titan's extreme conditions. On a daily basis, the temperature there is minus 179 degrees Celsius, the atmospheric pressure at the surface is ca. 1.5 times greater than the pressure of Earth's air at sea level, and the density of the atmosphere is ca. 4.5 times greater than the density of Earth's air at the surface – the land of the sea. Saturn's moon in its current form resembles Earth from billions of years ago. The space drone will move in a fully autonomous mode. This is related to Titan's distance from Earth. The data transfer time varies from 1 to 1.5 hours one way, which excludes control from the Earth. The *Dragonfly* will not be equipped with solar panels or batteries. NASA engineers decided to use a nuclear drive, or rather a radioisotope thermoelectric generator. The mission will take place as part of the New Frontiers program, which aims to study alien worlds located in the solar system.

UAVs are considered an important tool for planetary exploration because, among other things, they can correct errors when entering the atmosphere of celestial bodies; there will be many more possibilities to use them for space exploration. However, the design and construction of space drones should be carried out depending on the environment. Due to gravity on the surface of Mars, the weight of an UAV should be adapted to the type of energy used by this device. Dust storms on Mars are common; for unexplained reasons, some of them (about every decade) cover the entire surface of the planet. Such storms can pose a great threat to exploration equipment, as individual dust particles are very small and slightly electrostatic, and tend to adhere to surfaces with which they come into contact. For example, the solar panels of the Opportunity rover, sent by NASA in 2018, were completely covered with dust. This also argues for the use of nuclear propulsion for Mars devices (NASA, 2015).

On December 3, 2020, *the Ravn X* drone was publicly shown (via the Internet), a large unmanned aerial vehicle of the private company *Aevum*, which is to be used as the basic stage of the satellite object launching system. Its integral part will also be a light, two-stage space rocket (as the second and third segment of the entire carrier system). The biggest novelty of this drone is the use of a fully autonomous system – based on a large carrier unmanned platform. The airframe, which serves as the main segment, is nearly 24 m long and has a wingspan of almost 20 m, with a maximum total weight of nearly 25 tons (including payload). This device is powered by two turbo-jet engines, thanks to which it is to reach a cruising speed of up to 925 km/h and an altitude of over 18 km. Its task is to launch light rockets with satellites practically every 180 minutes – including the time needed to re-prepare and set up for the flight. The space drone uses traditional jet fuel and can take off and land in virtually any weather on the approximately 1 mile long landing pad.

The first U.S. Air Force mission will be launched from NASA's Wallops Flight Facility in Virginia. The initial launch capability of the ASLON-45 mission is scheduled for the third quarter of 2021.

Subsequently, flights related to the performance of the contract for the U.S. Air Force Space and Missile Systems Center are planned. This is related to the OSP-4 (*Orbital Services Program-4*) order submitted in October 2019 for implementation, in which 8 selected companies are to participate. The total value of this programme is USD 986 million – it assumes the execution of 20 space launches over a period of 9 years (Space24, 2020).

So far, the only space drone operating in the atmosphere of *Mars* is *Ingenuity* (weighing just over 6 kg), which has been exploring this planet since 2022; it is the first device to help the large Perseverance rover in its mission to search for signs of life. The rover noticed fragments of the capsule in which it had been locked during the trip to *Mars* in February 2022. The Ingenuity drone took pictures of the remains of the capsule on April 19, 2022, and these allowed obtaining valuable information needed for the planned "Mars Sample Return" mission, thanks to which samples of regolith from the surface of Mars will be delivered to Earth. To photograph the remains of the capsule, the space drone rose to a height of 8 m, flew 192 m and then took ten photos. Photographs were sent aboard the *Perseverance* rover, and through it to Earth (NASA, 2015).

Some believe that in the US the construction of space drone devices dates back to 2010. At that time it was an American military unmanned shuttle (the cost of its construction was then ca. 100 million dollars), which was the first flight into space. The secretly launched X-37B (called space bombers) was designed for the Air Force by United Launch Alliance, a joint venture between Boeing and Lockheed Martin; it is 9 meters long, has a wingspan of 15 meters and is powered by solar panels. Before the last launch of the shuttle, in May 2020, the Pentagon announced a series of scientific experiments that it intends to carry out with the use of this shuttle. The official mission was to verify how certain materials react in space and what the possibilities of converting solar radiation into radio-electric energy are. However, it can be assumed that this mission was primarily of a military nature (Chanock, 2013).

5. The use of nuclear energy in the operation of space drones under international law

5.1. Nuclear energy in space

Nuclear energy has been proven to be the most effective source of supply for deep space exploration, but the associated risks are significant. This was made clear by the accident of the Soviet maritime reconnaissance satellite *Cosmos* 954 in 1978. This satellite, powered by a reactor operating on uranium, crashed and its parts scattered over the territory of north-western Canada; subsequently 65 kg of radioactive parts became dispersed over an uninhabited terrain, scattering radioactive material over an area of 124,000 square meters. 12 major pieces of wreckage and only 1% of the nuclear fuel were found. Clean-up of the contaminated site cost Canada more than $14 million (Grasty, 1980).

All this resulted in the commencement of work on an international agreement on this matter. Currently, a real solution is a “soft law” agreement, such as principles or a code of conduct. These are temporary solutions but are often prove to be quite effective.

Two types of nuclear power are currently used in space: reactors and radioisotope sources. The radioisotope power supply system is called a nuclear battery, which provides propulsion and heat and allows the space object to undertake missions in an environment beyond the reach of solar energy, chemical batteries and fuel cells. There are two types of systems: RTG (*Radioisotope Thermoelectric Generators*) and ASRG (*Advanced Stirling Radioisotope Generators*). The RTG provides electrical power to the facilities through the decay of Plutonium-238 dioxide. This system was an important power source for space objects in the 1960s. Plutonium has a relatively low level of radiation, but is inefficient and cannot be used to power objects or devices with a higher power. The ASRG system converts the heat from Plutonium-238 into energy using a portable piston in a device called the *Stirling Engine*. This system is more efficient than the RTG to produce the same amount of power. It is still being tested and has not yet been deployed in space missions. NASA plans to use it on a mission that runs through the Moon, Saturn and Titan. China also uses Plutonium-238, while Russia uses Plutonium-210 (Breeze, 2018).

Another way to power space devices is to use atomic fission; this nuclear reaction releases a huge amount of energy in the form of heat. The power is transferred through the conversion system to produce electricity. These systems are cheaper than RTG, and the level of obtained power is higher, hence the possibility of using it for longer and more complicated missions. The Soviet Union has become specialized in this field. Nuclear sources must be designed to be usable both in launches and in the space environment and have a date of cessation of operation. Nevertheless, nuclear reactors installed on space objects still cause the most safety concerns.

5.2. Nuclear safety conventions

After the accident in Canada, the UN needed more than 10 years to prepare rules related to the use of nuclear energy in space. These rules, created in 1992, were an important step in the gradual construction of a legal regime for space activities. However, it was only in 2009 that the Scientific and Technical Subcommittee and the IAEA (*International Atomic Energy Agency*) published a joint document entitled "Safety Framework for Nuclear Power Source Applications in Outer Space". None of these documents are binding. They serve more as guides and recommendations for countries that carry out space activities. International conventions remain the "hard law": IAEA and space conventions; "soft law" – rules from 1992 and the safety framework from 2009. The four IAEA conventions can be applied to countries with NPS (*nuclear power sources*) in space when they apply to pre-launch or post-launch operations.

The Convention on Early Notification of a Nuclear Accident was adopted after the Chernobyl disaster in 1986; 119 countries signed it. Article 2 deals with accident notification of individual countries (either directly or through the IAEA) that may be physically affected by a nuclear accident and information on minimizing the radiological consequences in these countries. The Convention also provides assistance and support to affected states (UN, 2009).

The Convention on Nuclear Safety, signed in Vienna in 1994, obliges states operating terrestrial nuclear sources to maintain a high level of safety by establishing international indicators based on IAEA rules that states should follow. The Convention is also about state cooperation, not sanctions or controls. The most innovative solution of the convention is the "peer review" mechanism, in which each state is obliged to periodically report on the steps taken with regard to the convention and its provisions; those reports were to be submitted to other sites for review. Article 3 of the Convention states that it applies to the safety of nuclear installations. It follows from it that the Convention does not apply to the supply of technical equipment in outer space (Convention on Nuclear Safety, 1994).

The CPPNM Convention (on Physical Protection of Nuclear Material and Nuclear Facilities) of 1979 is the only legally binding instrument on the physical protection of nuclear material revised in 2005, which protects nuclear devices and materials used for peaceful purposes in their storage and transport (which can be applied to the NPS in terms of protecting nuclear material from being launched or returning from space) (www.ns.iaea.org).

5.3. Outer Space Conventions and Nuclear Power Sources

The *Outer Space Treaty* (OST) refers to the prohibition of nuclear weapons in Article IV, and on the other hand, Article VI provides for the responsibility of the state for space activities (including non-governmental organizations; when the activity is carried out by an international organization, the responsibility is borne by the states that are its members); Article VII indicates the principles related to state responsibility in launches. States launching an object containing nuclear sources will also be liable for damage caused to another State or to its nationals or legal entities. Article IX is the only one that refers to the environment protection in space. Furthermore, if a state suspects that other entities are undertaking activities potentially causing harmful interference, it will have the right to be consulted. To date, no country has requested consultations before using nuclear sources in a space facility.

The 1972 Liability Convention does not contain any provisions that explicitly refer to NPS, although the term space object may refer to a space object and its devices (e.g. RTG or nuclear reactor). The Astronaut Rescue Agreement and its Articles 5(4) refer to nations that provide their space facilities with *nuclear power sources* (NPS) (Qizhi, 1986). It seems that the clarification about the usage of NPS in international space law is still necessary.

6. Conclusion

Efforts in space development have become significantly intensified over the last decade and have led to the need for new ways of studying planets and other celestial bodies. The modern trend is to create space devices capable of exploring the surface of a celestial body in a more precise way; this is where space drones can prove to be most useful. As the experience with unmanned aerial vehicles shows, these devices are relatively cheap, versatile, characterized by agility, speed, hovering, avoiding obstacles, tracking and following a target. In principle, any class of existing unmanned aerial vehicles can be considered suitable for space applications. Nevertheless, space drones must meet other climatic requirements prevailing on celestial bodies. Therefore, when designing such devices, a number of factors and limitations should be taken into account. The tendency of designers to use atomic energy in space drones may have far-reaching adverse effects on the space environment. Therefore, it is necessary to consider developing other ways to power them. As previous experience shows, such possibilities do exist. It is also necessary, much more than in the case of unmanned aerial vehicles, to control the state over space drones. As already indicated in this article, space technology is advancing, but the law does not seem to keep up with it. There is a strong need to provide some international space law to regulate space drones activity in outer space (including NPS). It is also necessary to define what a space drone is. Space organizations (such as UNCOPUOS) might act as driving forces for the development of space law (similarly to ICAO), adapted to the development of industry and technology (as the Aviation law). Space law should be an effective regulator to ensure the sustainable development of space.

References

1. Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (Polish Journal of Laws/Dz.U. of 1969 No. 15, item 110).
2. Breeze P., (2018). Chapter 4 – Piston Engine Combined Heat and Power Systems. In: *Combined Heat and Power*, pp. 33–40. doi.org/10.1016/B978-0-12-812908-1.00004-3).
3. Chanock A., (2013). The problems and potential solution related to the emergence of Space Weapon in 21st Century, *Journal of Air and Law Commerce*, vol. 78, issue 3, pp. 691–710.
4. Commission Implementing Regulation (EU) 2021/664 of 22 April 2021 on a regulatory framework for the U-space (OJ EU.L.2021.139.161).
5. Convention on Nuclear Safety, Vienna 20 September 1994 (Polish Journal of Laws/Dz. U. 1997 No. 42, item 262).
6. Convention on Registration of Objects Launched into Outer Space 1975 (Polish Journal of Laws/Dz.U. from 1979, No. 5, item 22).
7. FAA (2022). https://www.faa.gov/uas/recreational_flyers/knowledge_test_updates [23.01.2023].
8. Farand A., (2003). Commercialization of International Space Station Utilization: The European partner's Viewpoint, *Air and Space Law*, vol. XXVIII, no. 2, pp. 83–88.
9. Foster W.F., (2007). The Convention on International Liability for damage caused by space object. In: R.S. Jakhu (ed.), *Space Law – General Principles*, Montreal: McGill University, vol. II.
10. Franke, U.E., (2015). The global diffusion of unmanned aerial vehicles (UAVs) or 'drones'. In: Aaronson, M., Aslam, W., Dyson, T., & Rauxloh, R. (eds.). (2014). *Precision Strike Warfare and International Intervention: Strategic, Ethico-Legal and Decisional Implications* (1st ed.). Routledge. https://doi.org/10.4324/9781315850528.
11. Grasty R.L., (1980). The Search for COSMOS-954. In: *Search Theory and Applications*, (eds.) K.B. Haley, L.D. Stone, pp. 211–220. DOI: 10.1007/978-1-4615-9188-7_20.

12. Hermida, J., (2004). *Legal basis for a national space legislation,* Dordrecht, Boston: Kluwer Academic Publishers, pp. 62–67.
13. Hobe, S., (2019). *Space Law*, Baden-Baden: Nomos, pp. 69–88.
14. https://www.icao.int/meetings/uas/documents/circular%20328_en.pdf. [12.01.2023].
15. https://www.icao.int>safety/pages. [01.02.2023].
16. https://nauka.tvp.pl/58264848/wahadlowiec-w-ogniu-mija-20-lat-od-katastrofy-promu-columbia. [08.02.2023].
17. https://www.gov.pl/web/infrastruktura/miej-drony-pod-kontrola--od-31-grudnia-nowe-zasady-lotow-dronami-w-calej-europie. [09.02.2023].
18. Jakhu, R.S., (2007). *Fundamental principles of international space law*. Makau conference 16–17 June 2007.
19. Komputer Świat (2022). https://www.komputerswiat.pl/aktualnosci/nauka-i-technika/dron-ingenuity-sfotografowal-szczatki-na-marsie-niesamowite-zdjecia-wideo/vmskhcx [21.02.2022].
20. Lee, R.J., (2006). The liability convention and private space launch services – domestic regulatory responses, *Annals of Air and Space Law*, vol. XXXI, p. 351.
21. Leister, V., Frazier, M.C., (2000). *The role of national and international law in the regulations of space activities.* Proceeding of the 43rd Colloquium on the Law of Outer Space International Institute of Space Law of the International Astronautical Federation, Rio de Janeiro, 2–6 October 2000.
22. Martyniuk, K., *Rosyjskie balony, które jako jedyne latały na innej planecie*. https://rosyjski.pro/rosyjskie-balony-ktore-jako-jedyne-lataly-na-innej-planecie/ [23.02.2022].
23. NASA (2015). https://mars.nasa.gov/news/1854/the-fact-and-fiction-of-martian-dust-storms/. [23.02.2022].
24. NASA (rok) https://mars.nasa.gov/technology/helicopter/#. [12.01.2023].
25. O'Brien, D., (2021). *Closing the gap in space law: An implementation agreement for the Moon Treaty that supports all private activity while protecting essential public policies*, Global Space Exploration Conference (GLEX 2021), St. Petersburg, Russian Federation, 14–18 June 2021.
26. Odkrywcy planet (2018). https://odkrywcyplanet.pl/wenus/. [12.01.2023].
27. Oosterlink, R., (1995). Registration of space object. New developments. In: E. Pałyga (ed.), *International Space Law – Miscellanea, liber amicorum honouring professor Andrzej Gorbiel, PhD*, Koszalin, pp. 107–113.
28. Qizhi H., (1986). Towards a New legal regime for the use of Nuclear Power Sources in Outer Space. *Journal of Space Law*, no. 2, p. 95.
29. Pazmińo, L.F., (2021). *The International Civil Operations of Unmanned Aircraft System under Air Law*, Amsterdam: Wolters Kluwer, p. 23.
30. Plaza, J., (2021). A Drone on Mars: That's One Small Flight for a Drone, One Giant Leap for Drone Kind. https://www.commercialuavnews.com/surveying/a-drone-on-mars-that-s-one-small-flight-for-a-drone-one-giant-leap-for-drone-kind. [23.01.2022].
31. Reynolds, G.H., (2005). Space law in its second half century, *JSL 31*, no 2, p. 414.

32. Space24 (2020). https://space24.pl/pojazdy-kosmiczne/dron-do-wynoszenia-rakiet-kosmicznych-ravn-x-pokazany-swiatu. [23-01-2022].
33. Tate L., (2006). The status of the outer space treaty at International law during "war" and "those measures short of war", *Journal of Space Law*, vol. 32, no. 1.
34. Vyshnovetska, S., Melnyk, V., (2020). Unmanned Spacecraft and Space Drones as the Challenges for Space Law, *Philosophy and Cosmology*, vol. 24, pp. 39–47. DOI:10.29202/phil-cosm/24/4.
35. UN (2009). Safety Framework for Nuclear Power Source Applications in Outer Space, jointly published by the United Nations Committee on the Peaceful Uses 2009.
36. https://www.iaea.org/publications/documents/conventions/convention-physical-protection-nuclear-material-and-its-amendment. [07.02.2023].

TECHNICZNE I PRAWNE PROBLEMY Z DRONAMI KOSMICZNYMI

Abstrakt

W artykule przedstawiono przykłady wyzwań prawnych i technicznych związanych z dronami kosmicznymi. Temat ten jest pionierski, ponieważ prawo kosmiczne (bez definicji obiektu kosmicznego lub drona kosmicznego) stara się podążać za rozwijającą się technologią kosmiczną. Drony kosmiczne mogą być użyte do badań Marsa, Wenus i innych ciał niebieskich. Te dwie pierwsze planety były badane jeszcze w XX w.; tak np. atmosferę Wenus zbadały dwa balony. Przed kilku laty pojawiła się koncepcja zastosowania w misjach kosmicznych bezzałogowych statków powietrznych. 19 kwietnia 2022 r. udało się przeprowadzić udany eksperyment z pierwszym niewielkim kosmicznym dronem marsjańskim *Ingenuity*; wykonał on dziesięć zdjęć (rozbitego lądownika), które zostały przesłane na pokład łazika *Perseverance*, a przez niego na Ziemię. Obecnie trwają prace nad większymi dronami kosmicznymi; jeden z projektów dotyczy platformy do wystrzeliwania statków kosmicznych z wysokości 18 km nad Ziemią, inny dotyczy użycia napędu atomowego w dronach kosmicznych. Wygląda jednak na to, iż prawo nie nadąża za rosnącą technologią kosmiczną. Plany zastosowania dronów kosmicznych mogą napotkać wiele trudności z racji nieprecyzyjności i luk międzynarodowego prawa kosmicznego oraz konieczności oparcia się na prawie *miękkim*, czyli przepisach i zaleceniach, których przyjęcie zależy od dobrej woli państw. Poza tym stosowanie analogii do przepisów dotyczących bezzałogowych statków powietrznych (UE, ICAO) może nie zawsze być możliwe. Ponadto obecnie nie ma literatury ani przepisów dotyczących dronów kosmicznych, co jest wyzwaniem dla międzynarodowych prawników. Prawo lotnicze i organizacje lotnicze zajmujące się bezzałogowymi statkami powietrznymi to dobre przykłady do naśladowania przez legislatorów kosmicznych.

Słowa kluczowe: bezzałogowe statki powietrzne, drony kosmiczne, prawo kosmiczne, energia atomowa