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Space and Security

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ABSTRACT

The human presence in outer space presents both exciting opportunities and significant security challenges. This thesis examines the evolving security landscape surrounding space activities. It analyzes the risks associated with the increasing number of satellites in Earth's orbit, including potential collisions and debris generation. Additionally, it explores the potential for weaponization of space and its consequences for international security.

Furthermore, the thesis examines the role of satellites in both military and civilian applications. It analyzes the tactical advantages satellites provide to armed forces and discusses their use in supporting missions and operations.

Finally, the thesis investigates the history of the Space Race during the Cold War and its impact on space security concerns. It concludes by discussing current and future security challenges associated with space exploration, and analyzes diplomatic efforts to prevent conflict and ensure the peaceful use of outer space.

SUBJECT AREA: satellites, space security, military and security operations

KEYWORDS: types of orbits, types of satellites, operational purposes of Earth orbits, satellites for defence purposes, satellites for security purposes, security from Space, security in Space

ΠΕΡΙΛΗΨΗ

Η ανθρώπινη παρουσία στο διάστημα παρουσιάζει τόσο συναρπαστικές ευκαιρίες όσο και σημαντικές προκλήσεις ασφαλείας. Αυτή η διατριβή εξετάζει το εξελισσόμενο τοπίο ασφαλείας που περιβάλλει τις διαστημικές δραστηριότητες. Αναλύει τους κινδύνους που συνδέονται με τον αυξανόμενο αριθμό δορυφόρων σε τροχιά γύρω από τη Γη, συμπεριλαμβανομένων πιθανών συγκρούσεων και παραγωγής διαστημικών σκουπιδιών. Επιπλέον, εξετάζει το ενδεχόμενο εξοπλισμού του διαστήματος και τις συνέπειές του για τη διεθνή ασφάλεια.

Επιπροσθέτως, η διατριβή εξετάζει τον ρόλο των δορυφόρων τόσο σε στρατιωτικές όσο και σε πολιτικές εφαρμογές. Αναλύει τα τακτικά πλεονεκτήματα που παρέχουν οι δορυφόροι στις ένοπλες δυνάμεις και συζητά τη χρήση τους για την υποστήριξη αποστολών και επιχειρήσεων.

Τέλος, η διατριβή διερευνά την ιστορία του Διαστημικού Ανταγωνισμού κατά τη διάρκεια του Ψυχρού Πολέμου και τον αντίκτυπό της στις ανησυχίες για την ασφάλεια του διαστήματος. Συμπεραίνει συζητώντας τις τρέχουσες και μελλοντικές προκλήσεις ασφαλείας που σχετίζονται με την εξερεύνηση του διαστήματος και αναλύει τις διπλωματικές προσπάθειες για την πρόληψη συγκρούσεων και την εξασφάλιση της ειρηνικής χρήσης του εξωδιαστήματος.

ΘΕΜΑΤΙΚΗ ΠΕΡΙΟΧΗ: (εγγύς) διάστημα, δορυφόροι, ασφάλεια διαστήματος, στρατιωτικές επιχειρήσεις και επιχειρήσεις ασφαλείας

ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ: είδη τροχιών, είδη δορυφόρων, επιχειρησιακές χρήσεις των γήινων τροχιών, δορυφόροι για σκοπούς άμυνας, δορυφόροι για σκοπούς ασφαλείας, ασφάλεια από το Διάστημα, ασφάλεια στο Διάστημα

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Απαγορεύεται η αναδημοσίευση, αναπαραγωγή, ολική, μερική ή περιληπτική ή κατά παράφραση ή διασκευή ή απόδοση του περιεχομένου της παρούσας διπλωματικής εργασίας με οποιονδήποτε τρόπο, ηλεκτρονικό, μηχανικό, φωτοτυπικό ή άλλο, χωρίς την προηγούμενη γραπτή αναφορά συγγραφέα. Νόμος 2121/1993 και Νόμος 3057/2002, ο οποίος ενσωμάτωσε την Οδηγία 2001/29 του Ευρωπαϊκού Κοινοβουλίου και Κανόνες Διεθνούς Δικαίου που ισχύουν στην Ελλάδα.

In Memory of the Astrophysicist Dionysis Simopoulos,
who showed me the way to Space

"We are stardust and we will return to the stars"

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INTRODUCTION

During the past centuries, sky was the ultimate limit. Since then, humans had always had an exploring nature, which is validated by all the land and sea journeys around the Earth. The human desire was insatiable and had been satisfied by discovering new places and reaching to further unknown horizons.

It is highly undisputed though, that the very last century, humans made tremendous progress in science and technology. As a result, in this fraction of the timeline, on 17th December 1903, humans achieved to succeed one of the brightest achievements that had always been considered to overcome the limits of the impossible, the flight with the first manned airplane. Although the duration of this flight¹ was only 59 seconds and the distance covered just 260 meters (852 feet), the future of this invention seemed to be very promising and innovating.

After only 54 years, in the summer of 1957, the Soviets announced that in the next few months our planet would have had 2 satellites. At that moment, a huge majority could not accept this statement, as a possibility of such an event considered to be impossible, due to the current technological capabilities of the era. The rest are just history. On 4th October 1957, Space Age was inaugurated², as the first artificial satellite, named Sputnik 1 had been launched to orbit around Earth. The first unmanned space travel lasted 3 weeks.

U.S.A. responded on 31st January of 1958, by launching the first U.S. satellite, named Explorer. By then, the Soviets had already launched the satellite Sputnik 2, with the famous first “space” dog, Laika and continued their pioneering space achievements being first in the Space Age, by setting in orbit manned satellites (Yuri Gagarin was the first man in space), launching the first unmanned spaceship to impact the Moon, first to orbit the Moon, first to land on the Moon and first to impact Venus. But Americans, had not made yet their final move. On 20th July of 1969, U.S.A. set up the ultimate milestone on the human history with the Apollo 11 mission³, as Neil Armstrong and Buzz Aldrin made the first steps on the Moon surface.

But this was not the end of the human desire for further space achievements. In 1977, U.S.A. launched the Voyager program, running by two interstellar probes, Voyager 1 and Voyager that is still ongoing! The two probes after passing by the outer planets of our solar system, Jupiter, Saturn, Uranus and Neptune they continued their space travel and the last years they have been travelling beyond our solar system’s boundaries, continuing to collect and transmit useful data to Earth.

After making this special mention to the above human milestones in the Space, we will come to the more recent years. Space nowadays is a really crowded neighborhood. The last 50 years, thousands of satellites had been launched in orbit to perform useful operations for our daily life, such as communications, navigation, weather prediction, environment monitoring, scientific measurements, rescue etc.

Moreover, apart from the civilian use, satellites are used from governments and military forces with further purpose to preserve their sovereignty, support their defence, assure the security, and monitor the other countries, through gathering intelligence, transmitting and

¹ 1903 – The first Flight, accessed: 19/01/2023, available:

<https://www.nps.gov/wrbr/learn/historyculture/thefirstflight.htm>

² Sputnik launched, accessed: 19/01/2023. Available: <https://www.history.com/this-day-in-history/sputnik-launched>

³ Apollo 11 Mission Overview, accessed: 19/01/2023, available:

https://www.nasa.gov/mission_pages/apollo/missions/apollo11.html

receiving data and information, and monitoring the globe in real time. The satellites, as “eyes from the sky” can provide high resolution images and early warning for potential actions or incidents that should be taken into consideration. It should also be highlighted that the Cold War, the approximate period between 1947 – 1991, accelerated and made more intense the Space Race between U.S.A. and U.S.S.R., based on their ideological and geopolitical attempts for global influence.

Moving on, the recent years a new Space age was inaugurated, which is widely known with the term New Space (Space 2.0), where private commercial companies have made their appearance on the space market. Consequently, public and government sector are no longer the only actors in the space industry. Many enterprises like SpaceX, Blue Origin, Virgin Galactic etc. made their presence intense in this sector.

Last but not least, the future ventures are going to be of a greater status and ambition, as the human race will make the effort to inhabit the planet Mars, through the development and implementation of the “Mars Project”⁴. The initial goal of this Project is the landing of the Man on the planet Mars and in the future, the colonization of the Planet Mars.

Thus, the future of the human in the Space seems to be even more fruitful and fascinating. By developing new technologies and achieving new scientific accomplishments, it is certain that we are going to make huge steps to our future missions, especially at the direction of establishing an autonomous colony on Mars. All the scientific, innovational and technological route towards this direction is the new era of space research (Space 3.0)

This growth in space activities, while exciting, also raises security concerns. The increasing number of satellites creates the risk of collisions and debris. The potential for weaponization of space and competition for resources like asteroid mining pose additional challenges. This thesis will explore these security concerns and discuss how the international community can ensure the peaceful and sustainable use of outer space.

⁴ Issue #1(1) 2014 Astronautics , Space 1.0 to Space 3.0: from Gagarin to market growth, accessed: 19/01/2023, available:

https://room.eu.com/article/Space_10_to_Space_30_from_Gagarin_to_market_growth

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PREFACE

This Thesis is structured in five (5) chapters. The first chapter is an introduction to the Earth orbits that artificial satellites are placed after launching and there is a relevant explanation about the choice of a specific orbit for every satellite according to the designed mission and operational use.

The second chapter provides a description of the satellites as artificial objects. In the beginning there is a description about the satellite systems and subsystems. Following, there is an extensive description of the satellites according to their size – weight, their mission and their operation – mission (e.g. for communication, weather prediction etc.). Finally, there is a highlight for the use of satellites at the sector of defence and security.

In the third chapter there is an extensive report for the use of satellites at defence sector, cited certain real case study examples about how the satellites and their data – information supported armed operations.

The fourth chapter provides an insight about the use of satellites to the security sector and how their real-time information support important missions and daily human activities.

The fifth chapter focuses on the various categories of space weapons that can threaten the space security as well other volatile factors such as solar wind or space debris. Continuing there is a description for the Space Race during Cold War between USA and USSR from 1957 until 1975.

Closing, there is a report at the sixth and last chapter about some of the new challenges that the humans are facing and going to face in the future at space exploration and as well the diplomatic efforts for the avoidance of competition in Space.

PART A. ORBITS AND SATELLITES

1. Orbits

An orbit is the curved path that a natural or artificial object in space (e.g. star, planet, spacecraft, satellite etc.) takes around another (more massive) object due to force of Gravity.

In general, gravity affects the motion of objects in Space depending on the distance between them, according to Newton's law of gravity, making them to attract each other as a result. If the attraction produces the necessary momentum, the objects start orbiting each other. If the objects have a similar mass, then they seem to orbit around a common gravity point, while in the case that the objects have a big mass difference, the less massive object orbits around the more massive. The most characteristic example for the above-described conditions, are the orbit of Moon around Earth and the orbit of Earth around Sun, respectively.

It should be emphasized the fact that, despite the large mass difference, the heavier object is oscillated imperceptibly by the gravity interaction of the lighter object. For instance, this situation justifies the ocean tides. Respectively, our Sun is slightly disrupted from its course because of the planets and the other solar celestial bodies' existence and motion⁵ [1].

The man launches satellites and spacecrafts into space, with rockets that contain enough propellant to boost them and their payload above Earth's atmosphere, putting them into orbit around the Earth. As heavier is the launched payload, the more power and thus bigger rocket with even more amount of propellant is required to achieve that. When the rocket reaches the desired altitude, the payload is released into the Space [2].

The combination of the payload momentum and the Earth's gravity compels the payload to a constant orbiting around Earth. Following, gravity keeps the satellite on an almost stable - steady orbit, like the Earth keeps the Moon in orbit around itself. The absence of air and subsequently friction, makes it easier for a satellite to orbit around Earth without further human interference. Setting satellites into orbit enables us to use and exploit the full potential of technologies for telecommunication, navigation, weather forecast, science, and army and generally for many other aspects of humans' life [3].

Nowadays, several decades after the "conquer" of the Space, there is an increasing interest on the field of Space Science, that is being ascertained with a more and more intensive (orbital) circulation of satellites (telecommunication, meteorological, scientific, geodetic, military, etc.), moving at high velocities around the Earth. In total, more than 7500 artificial objects are in orbit [4] (space debris that will be mentioned in the next chapters of this thesis, are not included to this number), while in the near future, it is estimated an exponential increase at this number, as, at the moment, there is an intense activity not only from public – governmental sector but also from the private – enterprise one, such as SpaceX, Blue Origin, Virgin Atlantic etc.

⁵ ESA, Types of Orbits, Mar. 2020;

https://www.esa.int/Enabling_Support/Space_Transportation/Types_of_orbits

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As it is perceived, the Earth orbiting satellites are not at the same orbit. As Ajmal Yousuff, a Drexel University professor said, «Orbits are "roadways in space", you place a vehicle in space, and it stays there». The type of a satellite's orbit depends on its mission and the operational goals and needs. Satellites have different orbits because it depends on what each satellite is designed to accomplish. The Space is a vast place, however there are some main types of orbits that are used when satellites are launched.



Image 1: Inclination angle of orbits

[Source: The Physics of Space Security, A Reference Manual]

1.1 Types of orbits

Firstly, we should take into consideration that, in general, satellite orbits are ellipses. The three factors that are strongly bind with the satellite's orbit are the altitude (distance from Earth's surface), the orbital speed and the orientation of the orbit with respect to equator [inclination angle – the angle varies from 0° (equator) to 90° (pole)].

For instance, at the special case of a circular orbit, once studying the Earth – satellite (gravitational) system, we can easily conclude (by consulting the physics math expressions), that satellites orbiting at a low altitude, travel in orbit at a high speed to preserve their distance from Earth's surface. On the other hand, satellites orbiting at a high altitude, travel in orbit at a lower speed. Accordingly, the period of the orbit of the low altitude satellites is calculated at less than two (2) hours, whereas the period of high-altitude satellites can reach the twenty-four (24) hours.

However, due to the general orbit shape (elliptical) the altitude and the satellite's orbital speed vary with position around orbit (taking also into consideration the eccentricity). Thus, a satellite on elliptical orbit moves faster when it is closer to the Earth (perigee) and slower when it is to the farthest distance from Earth (apogee). Compared to the circular orbit, at this case, satellite's orbital speed varies. The same applies for the period time of the orbit.

Last but not of least importance is the amount of launch speed for a successful set-in orbit. According to the Newton's Laws of Motion and Universal Gravitation, if a satellite is launched from Earth with a speed of 11.2 km/s or greater, Earth's gravity is not strong enough to keep it in any type of orbit and it will escape into the Space.

Low Earth Orbit (LEO)

The Low Earth Orbit is the Space area that extends from 160 to 1000 kilometers [5]. The space boundary of a LEO is even higher, at some thousand kilometers, though most satellites are orbiting at the aforementioned distance from Earth's surface. A complete LEO orbit lasts approximately 90 to 120 minutes and therefore a LEO satellite, depending on its altitude, can complete from 12 to 17 orbits per day [6].

This area of space is most preferred due to the high radiation and charged particles that flows beyond this limit. Another important factor that should be taken into consideration for a satellite mission operating in LEO is the atmospheric drag, especially during periods of intense solar activity. At this point, the outer layer of Earth's atmosphere tends to expand, and therefore emerges a potential danger for the operation and orbit destabilization of the satellites that are orbiting at a few hundred kilometers altitude.

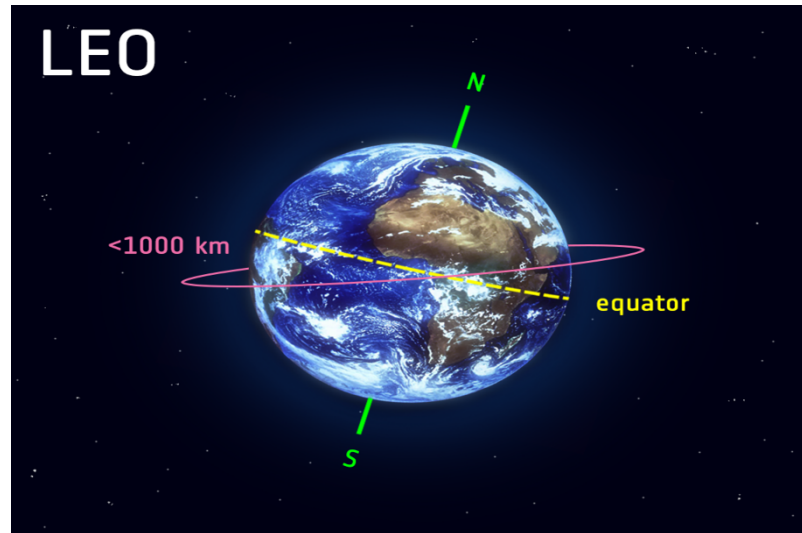


Image 2: Low Earth Orbit (LEO)

[Source: https://www.esa.int/ESA_Multimedia/Images/2020/03/Low_Earth_orbit]

Medium Earth Orbit (MEO)

The Medium Earth Orbit, also known as Intermediate Circular Orbit (ICO) is the space area that extends from 1500 to 36000 kilometers. On contrast with the LEO that in the vast majority are elliptical, this type of orbit is a circular one. One of the most common orbits of this type is set at the altitude of 10.000 kilometers, where a complete satellite's orbit lasts approximately 6 hours. One other orbit is the semi-synchronous orbit, set at the altitude of 20.000 kilometers and period of 12 hours. Satellites at these altitudes are moving slower and consequently the arrangements required are simpler and fewer compared to a satellite in LEO.

However, there are fewer satellites in MEO than LEO and the other types of orbits that are mentioned below, because of the presence of Van Allen radiation belts. The Van Allen belts are two "regions" surrounding the Earth consisting of relativistic electron and proton populations trapped in the Earth's magnetic field [7]. The inner belt extends from roughly 500 km to 5,500 km at the equator and the outer belt extends from 12,000 km to 22,000 km. The electrons and protons of the Van Allen Belts cause damage to satellites' onboard electronic systems and its' solar cells which results in a gradual reduction of the power output of solar power on satellites [8]. Thus, a consecutive passing of a satellite through the Van Allen Belts could lead to a total failure to the satellite's operation failure, so satellites at these altitudes are outfitted with shielding to lower the risk of damage during their operational lifetime.

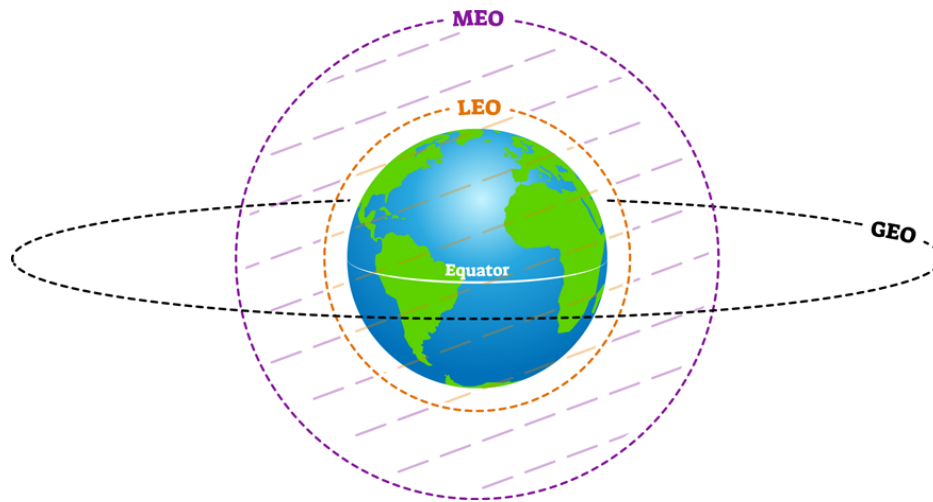


Image 3: Medium Earth Orbit (MEO)

[Source: <https://www.pivotel.com.au/our-networks/how-satellite-works/>]

Highly Elliptical Orbit (HEO)

Highly Elliptical Orbit (HEO) is an extremely elongated elliptical orbit, where the perigee is at a relatively low-altitude and the apogee at an extremely high-altitude apogee. The basic characteristic of this type of orbit is that a satellite in an inclined HEO spends a significantly greater time period over one Earth's hemisphere compared to the other, as a result of application of Kepler's second Law of planetary motion. On the contrary, satellites that move into other types of inclined circular/orbits spend an approximately equal amount of time in both hemispheres. Thus, a satellite can remain near apogee of a HEO for more than 12 hours. This type of orbits was first introduced by the Soviets to facilitate the coverage by Space to their vast country. In addition, the majority of Russia is at high latitude, therefore, HEO was very useful for the operational coverage of Russia's needs from Space, as other type of orbits could not provide at any case full coverage of this enormous region. This fact explain why the two most known HEO have Russian name, to wit, Molniya and Tundra Orbits. Furthermore, these two orbits provide polar coverage [9].

Molniya Orbit

This Molniya Orbit is a highly elliptical orbit, with a period of 12 hours and an inclination from the equator of approximately 63.4° . This type of orbit named after the Soviet communication satellites Molniya, which were constructed and developed in the mid 60's. The perigee of Molniya Orbit is at approximately 1000 kilometers, while its apogee reaches the 40000 kilometers. The period of this orbit is 12 hours, with apogee occurring over approximately the same high latitude point on Earth. For 8 of their 12-hour periods, the satellite remains visible to the regions under the apogee, with elevation angles above 70° . Molniya orbits are also used by U.S. intelligence services [10].

Tundra Orbit

Respectively with Molniya orbits, Tundra orbits have an inclination of 63.4° , but an apogee at a higher altitude. This type of orbit is used as well for coverage of high latitude areas. The main difference with Molniya orbit is that the period time of Tundra orbit is 24 hours. Accordingly, the time that satellite remains visible to the regions under the apogee rises to 12 hours. The perigee of a Tundra orbit is approximately 18.000 kilometres, while its apogee rises over 50000 kilometres [11].

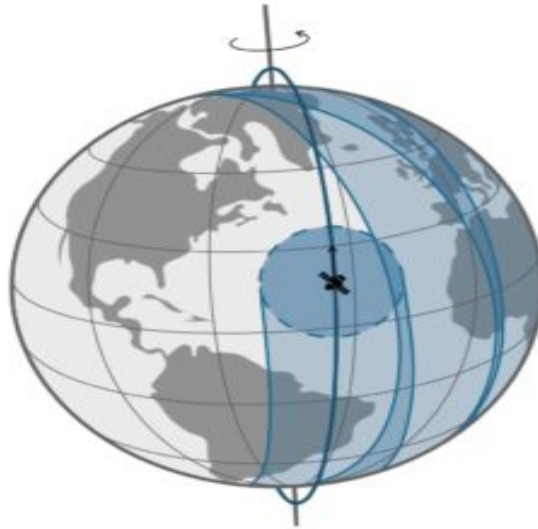


Image 4: Highly Elliptical Orbits (HEO)

[Source: <https://www.researchgate.net> - uploaded by Fritz Bekkadal]

Polar Orbit (PO)

Polar Orbit is an orbit with an inclination from 60° to 90° respectively from the equator. Essentially, this type of orbit is a LEO, however, the satellite at this case, moves constantly almost over the Earth's poles. Due to the rotation of the Earth, after each complete orbit, the satellite passes over different longitude points. The main advantage of this orbit is that in 24-hour period, a satellite observes every point on Earth twice. The polar orbit altitude varies from 200 to 1000 kilometers [12].

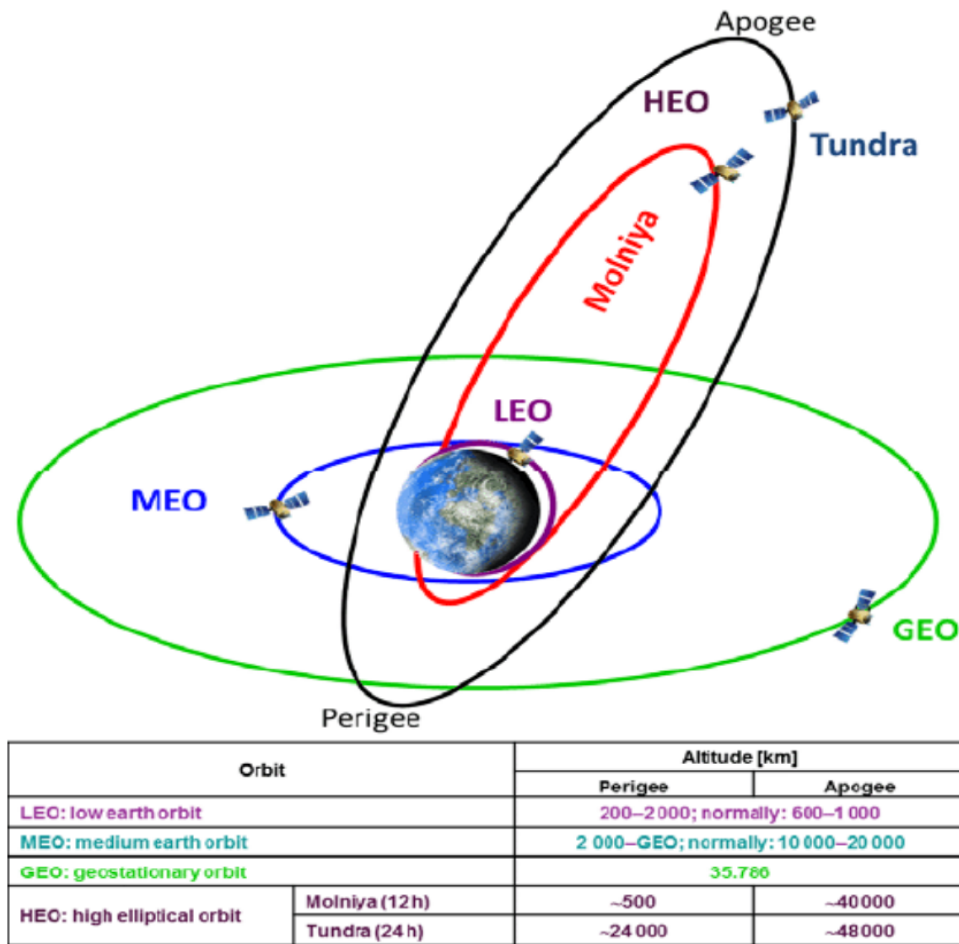


Image 5: Polar Orbit (PO)

[Source: Source: <https://aerospace.csis.org/aerospace101/earth-orbit-101/>]

Sun – Synchronous Orbit (SSO)

SSO or helio-synchronous orbit is considered almost a PO. At this type of orbit, satellites are moving at an altitude that varies from 700 – 800 kilometers, while the inclination of the orbit is set from 95° to 105° .

In addition v, satellites in SSO, are synchronous with the Sun. This means they are synchronized to always be in the same 'fixed' position relative to the Sun and therefore the satellite always passes over the same spot at the same local time – for example, passing the city of Athens every day at 2 pm exactly. Satellites in SSO may also be in LEO or MEO [13].

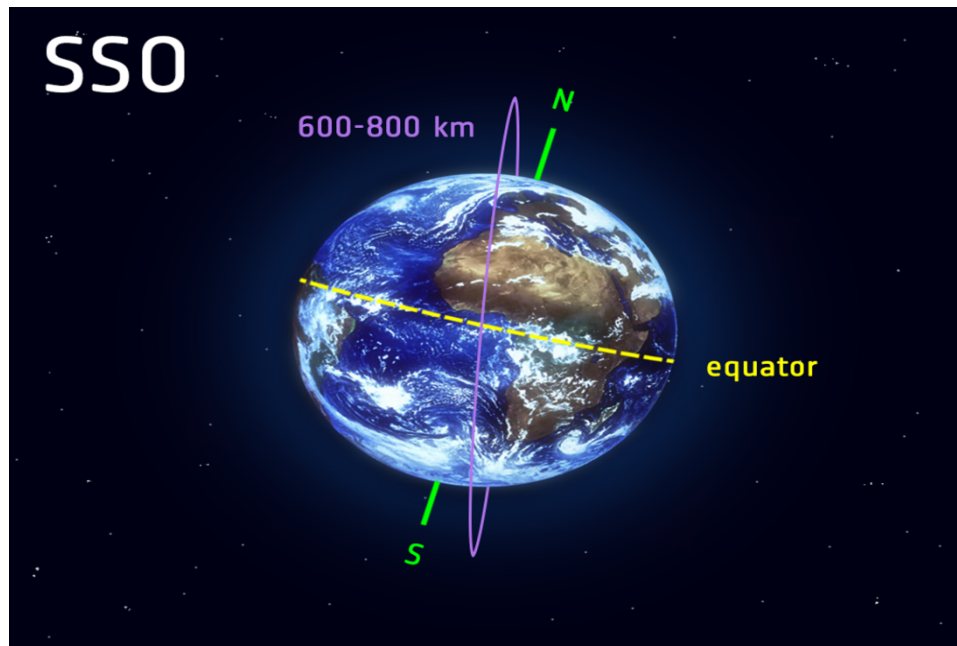


Image 6: Sun-synchronous orbit (SSO)

[Source: https://www.esa.int/ESA_Multimedia/Images/2020/03/Polar_and_Sun-synchronous_orbit]

Geo - Synchronous Orbit (GSO)

Geosynchronous orbit is significantly farther away from Earth than LEO or MEO. The altitude of this orbit rises to approximately 36000 kilometers. This fact allows satellites to match Earth's rotation and therefore the time needed for a complete orbit is almost equal to 24 hours (sidereal day). Satellites in this orbit, observe the Earth as if it were not rotating [14].

Geo - Stationary Earth Orbit (GEO)

This orbit is a special case and the most useful GSO, therefore the term GSO is often confused, usually without an issue, with the term GEO. The latter is considered the circular orbit, where the satellite orbits directly over equator at the altitude of approximately 35786 kilometers. This makes the satellite to be constantly over a specific geographical point. Because of this, satellites in GEO are constantly in the field of view for approximately one-third the Earth's surface. It should be emphasized that satellites in GSO operate outside the regions of the Van Allen radiation belts, however from time to time they are exposed to high-energy sun particles, thus there is a constant danger of damage or malfunction. GEO is the second most preferred orbit (35% of satellites) after LEO (55% of satellites) [15].

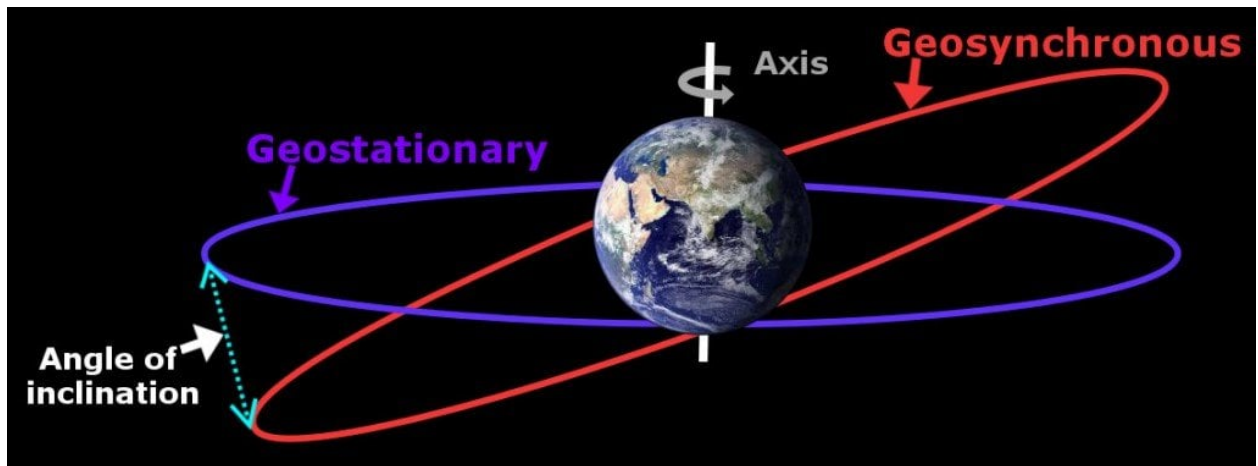


Image 7: Geo-stationary and Geo-synchronous orbits

[Source: <https://www.scienceabc.com/nature/universe/what-is-a-geosynchronous-satellite-and-how-is-it-different-from-a-geostationary-satellite.html>]

Lagrange Points (L-POINTS)

Lagrange points are five special locations in the Earth - Sun orbital plane. At these points, satellites orbit the Sun, however they maintain a fixed position relative to Earth's center of gravity. This peculiar situation was first discovered and expressed by the mathematician Joseph Lagrange, while studying the restricted three-body problem [16].

Lagrange points are caused by the balance between the gravitational fields of two large bodies, in our case Sun and Earth. So, satellites at these 5 points remain stable, like a cosmic ship that has dropped its anchor in the Space.

The three of these points, names as L1, L2 and L3 are unstable, thus, objects at these points require periodic orbital adjustments to maintain their position, whereas the other points, named as L4 and L5, are permanently stable. Lagrange points are ideal for orbits that are designed to perform in a very big distance from Earth while at the same time the spacecrafts/satellites are not carried away by other gravitational fields.

The most used Lagrange points are the L1 and L2. These are at 4-time Earth – Moon distance (approximately 1.5 million kilometers) [17].

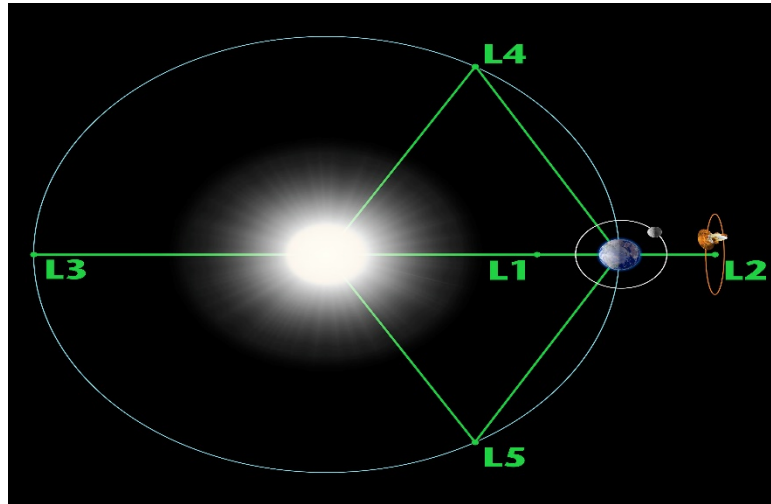


Image 8: Lagrange points

[Source: <https://solarsystem.nasa.gov/resources/754/what-is-a-lagrange-point/>]

Constellations

Constellations are groups of satellites that orbit the Earth in similar, but suitably shifted or rotated trajectories. A very well known, widely used in our daily life is the Global Positioning System (GPS). Respectively, there is the GLONASS the Russian counterpart of the United States' Global Positioning System, and other satellites' constellation such as IRIDIUM, Globalstar, ICO, ORBCOMM and Teledesic [18]. The very last years and as of late May 2021, SpaceX had launched more than 1,730 Starlink satellites overall which provide broadband service in select areas around the world, as part of a beta-test program.

All these constellations have been utilized, when it was perceived, that LEO could be more efficient and producing for communications compared to the traditional GEO. However, in LEO, constellations require regular orbital control maneuvers to avoid a change in the relative configuration and alignment of satellites [19].

Furthermore, the presence of CubeSats rise exponentially the number of satellites over, as their small size allows a large number of small sized satellites to launch at the same time, whereas, in the past there could be launched only one or two satellites at a time. Indicatively, the private sector is a key actor to constellations formation. For instance, the SpaceX Starlink satellite constellation, where, only on May 2021, SpaceX launched 172 satellites in just three launches rising their constellation to a total number over 1600 satellites. The estimated number of Starlink satellites in orbit by April 2024 is around 6100. In addition, the UK Government part-owned OneWeb has launched 72 satellites in 2021. The number of OneWeb satellites in orbit by April 2024 is around 681.

In the near future, to name a few more companies, Kuiper (a subsidiary of Amazon), and Lightspeed, from Canadian company Telesat are planning to launch satellite broadband constellations ranging from several hundred to a few thousand satellites.

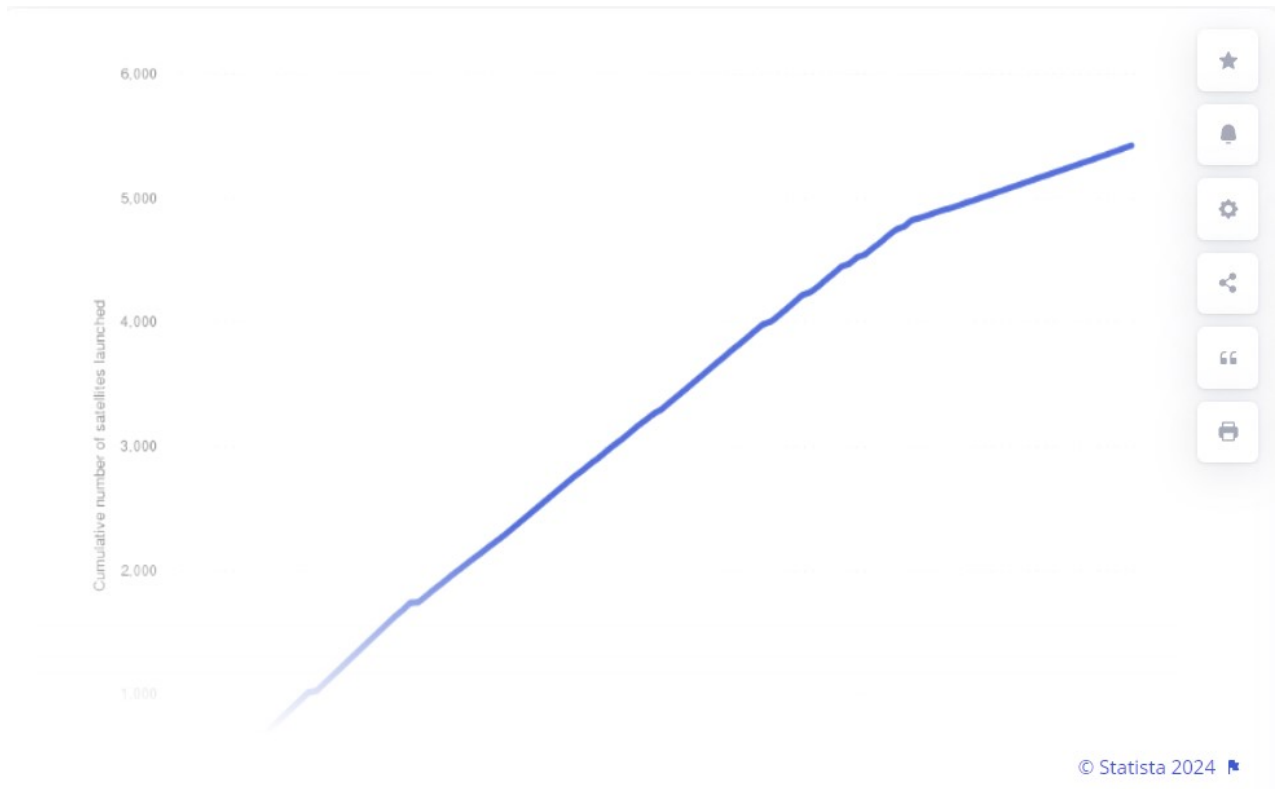


Figure 1: The estimated number of Starlink satellites in orbit by April 2024 is around 6,100.

[Source: <https://www.statista.com/statistics/1224164/starlink-satellite-launches/> (Accessed April 8, 2024)]

1.2 The operational purposes of Earth orbits

Low Earth Orbit (LEO)

The “low” orbit altitude combined with the orbital velocity is ideal for remote sensing missions, as well for the observation of the Earth. In addition, LEO is commonly used for communications, remote sensing satellite systems, military reconnaissance, spying and other imaging applications and manned spaceflight. Thus, it is not a coincidence that over the 50% of the total satellites is operating in LEO.

For instance, some of the satellites that use the LEO, are the International Space Station (ISS) whose orbit is at an altitude of approximately 400 km (Earth’s magnetic field protects the human from cosmic radiation and solar activity), the NOAA operates a series of weather satellites in polar orbits at 850 km altitude, and Iridium operates a series of 66 communication satellites in orbits at 750 km altitude.

In general, in LEO, satellites that are made for communications benefit from the lower propagation delay and consequently and less latency. Another benefit is that the small distance from Earth’s surface permits the resolve of small dimension subjects with greater detail.

However, the combination of the narrow area coverage (at a single moment) with the fast orbital velocity (and thus little time over the same area) necessitates a constellation of satellites for some applications that need real time data transmission and high area coverage, in order to overcome these obstacles and achieve the defined goals.

Medium Earth Orbit (MEO)

MEO is commonly used for navigation systems, such as Navstar GPS, GLONASS, BeiDou and Galileo. MEO constellations have been deployed to deliver low-latency, high-bandwidth data connectivity to service providers, government agencies, commercial enterprises and bring fibre-like performance to remote areas where laying fibre is not viable. All these satellite systems use a constellation of multiple satellites to provide coverage across large parts of the world all at once.

The main advantage of this orbit is, that compared to LEO, less satellites are needed for a specific operation (wider area of coverage) and consequently the needs and the expenses for the systems design are less. However, MEO satellites must employ radiation – hardened components (for their computer systems’ protection) to survive long term.

As an example, the U.S. GPS operates a constellation of 24 satellites in six orbital planes at an altitude of approximately 20,180 km. The Russian GLONASS system operates a constellation of 24 satellites in three MEO planes at an altitude of 19,100 km. The Chinese BeiDou operates a constellation of 35 satellites at an attitude of 21,150 km, in addition to five geostationary satellites. The European Galileo system operates a constellation of 24 satellites at an altitude of 23,200 km. Thus, over 100 satellites operate at altitudes between 19,100 km and 23,200 km, providing PNT (Positioning, Navigation and Timing) capabilities to a wide variety of military, civilian, and commercial users.

Geosynchronous Orbit & Geostationary Orbit (GSO & GEO)

GSO and GEO are used for many applications including, direct broadcast, telecommunications, relay systems, television, radio broadcasting, Earth observation and weather-based applications. Satellites in these orbits have the advantage of remaining over one spot on Earth, as both Earth and the satellite rotate about Earth's axis at the same rate. Three satellites can provide worldwide coverage, excluding the Polar Regions. These orbits allow the constant observation of a large region and therefore changes over big time periods can be traced, which is really useful for military operations.

For example, a GSO's satellite can observe, survey, and take images of an area of interest continuously. In addition, the communications of military forces can be extended, and their coverage can cover all the planet, and consequently remote troops, ships, and other vessels. Communications for civilian use also benefit from GEO orbit, as a single satellite can cover about 40% of the Earth surface. There are numerous companies that provide telephone, Internet, television, radio broadcasting and other services, as data are transferred at real – time over a wide geographic area without using a store-and-forward scheme.

Polar Orbit & Sun-Synchronous Orbit (PO & SSO)

PO is used for satellites providing reconnaissance, weather tracking, measuring atmospheric conditions, along-term Earth observation and military applications (e.g. spying). The PO satellites are very useful in applications where the field vision of the entire earth is required in a single day. Since the entire earth moves below them, this can be done easily. They are used in weather applications where predicting weather and climate-based disasters can be done in a short time.

For instance, Polar Orbiting Environmental Satellites (POES) offers the advantage of daily global coverage, by making nearly polar orbits 14 times per day approximately 520 miles above the surface of the Earth. The Earth's rotation allows the satellite to see a different view with each orbit, and each satellite provides two complete views of weather around the world each day.

Regarding the SSO, it ensures that satellites are synchronous with the sun, meaning that they pass over an Earth region at the same local time every day. This is ideal for long term observation and the imaging of a specific area at a specific time of day, for weeks, months, even years. Therefore, useful conclusion can be noted on weather patterns that emerge, prediction of weather storms, monitoring emergencies like forest fires or flooding, or data accumulation for long-term problems like deforestation or rising sea levels.

Highly Elliptical Orbit (HEO)

HEO is used for communications, satellite radio, remote sensing and other applications. This extremely elongated orbits with the advantage of long dwell times during the approach to and descent from apogee are very useful for communications satellites, signal collection and Earth monitoring. This type of orbit has the advantage of requiring less insertion energy than geosynchronous orbits, but it comes with the disadvantage that antennae must be steerable to maintain Earth pointing. For instance, the Sirius Satellite Radio system

operates three satellites to maintain two satellites over North America to provide its broadcast service. Molniya orbits are also used by U.S. intelligence satellites that monitor Russia and by Russian early warning satellites that watch for U.S. missile launches.

Lagrange Points

Lagrange points, especially L2 point, due to the stability that provide to satellites are ideal for scientific studies and the observation of the Universe. In these points, there are satellites such as NASA's WMAP (Wilkinson Microwave Anisotropy Probe) and European Space Agency's Planck mission. It is vital for these satellites, that their missions include the imaging of deep Space, to be placed at these distanced points, because otherwise, Earth's visible light and infrared radiation reflection obscures the telescope to detect and collect the limited light coming from distant space objects. Thus, imaging the infinite dark space next to a luminous planet would be of no worth and the results would be very poor.

Many ESA observational and science missions, are, or will enter an orbit about the L- points. For example, the solar telescope SOHO and LISA Pathfinder are at the Sun-Earth L1 point; Herschel, Planck, Gaia, Euclid, Plato, Ariel, JWST, and the Athena telescope are and will be at the Sun-Earth L2 point.

ORBIT	ALTITUDE*	USES
Low Earth Orbit (LEO)	Up to 2,000 km	- Communications - ISR - Human Spaceflight†
Medium Earth Orbit (MEO)	Approx. 2,000 to 35,000 km	- Communications - Position, Navigation, and Timing
Highly Elliptical Orbit (HEO)	LEO altitudes at perigee (nearest to Earth) Approx. 40,000 km at apogee (farthest from Earth)	- Communications - ISR - Missile Warning
Geosynchronous Earth Orbit (GEO)	Approx. 36,000 km	- Communications - ISR - Missile Warning

* The advantages of higher orbits for communications and ISR are near-persistent coverage of most of the Earth in view of the satellite, but limited access to polar regions. LEO satellites cover all parts of the world, including the poles, but for shorter periods based on the speed of the satellite.

† With the exception of nine U.S. Apollo missions to the Moon, all human spaceflight has been completed in LEO.

Figure 2: Military Satellite orbits and major orbital characteristics

[Source: Challenges to Security in Space, Defence Intelligence Agency, 2019]

2. Satellites

Since the successful launch and orbit of the very first artificial satellite, Sputnik, in 1957, much have changed these almost past 60 years, regarding the satellite's construction, their missions, their potential et cetera.

Sputnik was launched from Baikonur Cosmodrome in Kazakhstan. Sputnik in Russian language means satellite (when it is referred to astronomy). The Sputnik 1 satellite was essentially an aluminum sphere (58 cm diameter), 83 kg mass, consisting of 4 antennas attached to the sphere to the same side. The mission of the first satellite was elementary and of an identifying purpose, and therefore it was limited to the gathering of data of the upper layers of Earth's atmosphere, the propagation of radio signals in the ionosphere and the environment's temperature. The satellite was fully operating for about three weeks and after orbiting for a total of 3 months was finally burned by re-entering Earth's atmosphere, having completed approximately 70.000.000 kilometers (1400 Earth orbits) [20].

After this breakthrough, the era of satellites launching began and nowadays thousands of satellites have been launched in orbit around Earth. Of course, nowadays, satellites come in all shapes and sizes and their altitudes and designs depend on their purposes. Thus, satellite must be designed specifically to fulfill their role. The various types of satellites are listed below.

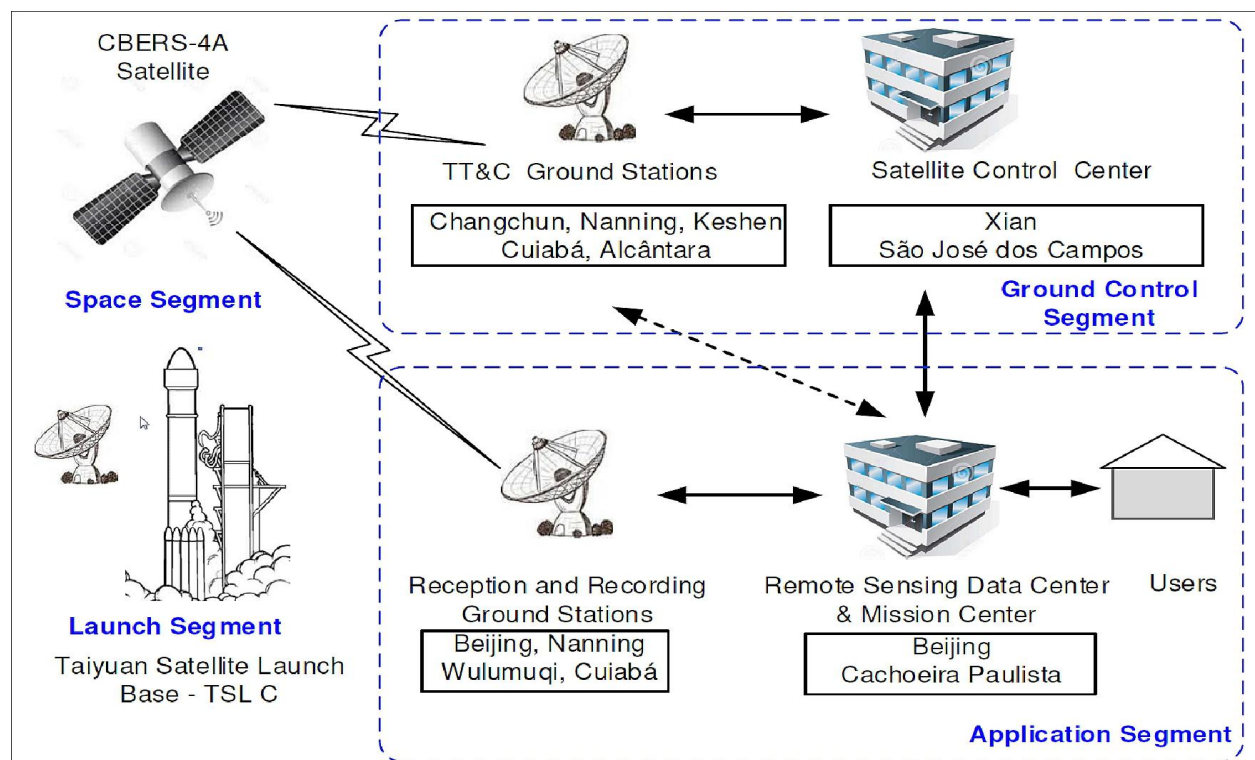


Image 9: Example overview of a Space, Launch & Ground Control Segment

Source: [<https://www.eoportal.org/satellite-missions/cbers-4a#mission-status>]

2.1. Satellites systems and subsystems

Currently, after five decades of humans' active presence to Space there are thousands of active satellites orbiting around the Earth. As it is already mentioned, the altitude and the satellite technical characteristics vary, depending on the mission that satellites are designed for and the purpose that are oriented to operate. However and regardless all the preceding, every satellite is made of the same basic systems and subsystems, in order to function properly and for a long time, achieving its predesigned mission.

A satellite system is a complex assembly of various components that work together to achieve a specific mission. The main parts of a satellite system can be divided into three categories: the space segment, the ground segment and the launch segment.

Space Segment

The space segment consists of the satellites orbiting Earth, which can be categorized into subsystems:

- a. **Mechanical Structure or Bus:** This provides the satellite's structural integrity, housing and attaching all components and subsystems, shielding them from the Space environment. It also plays a crucial role in thermal control and maintaining the satellite's orientation.
- b. **Propulsion:** Satellites do not need constant fuel or chemical energy to keep moving/orbiting, as Earth's gravity field take cares of this aspect. However, sometimes short-time and small movement's alterations are needed, which are serviced by the propulsion subsystem. This is responsible for orbit insertion, maintaining the satellite's orbital position, and conducting any necessary orbital maneuvers. This subsystem typically includes thrusters, propellant storage tanks, and associated control systems [20].
- c. **Power:** Satellites rely on power subsystems to generate and store energy. Most satellites use solar panels for power generation (electricity). In addition, there are attached batteries that store some of the absorbed energy to support the necessary operational needs when the satellite passes through the shadow of the Earth (eclipse) or when sunlight is insufficient.
- d. **Thermal Control:** The thermal control subsystem ensures that the satellite's components and subsystems remain within their operational temperature range. More specifically, this subsystem controls and adjusts the reflection and the re-radiation of the incoming and outgoing temperature, due to the satellites exposure to Sun and the heat that produce the satellite's components while operating (cooling mechanisms and heating systems). This is achieved through passive and active methods, such as thermal coatings, insulation, heaters, and radiators.
- e. **Attitude and Orbit Control System (AOCS):** The AOCS maintains the satellite's right orientation and ensures that it remains in the desired orbit. This subsystem typically includes reaction wheels or control moment gyroscopes, along with various sensors (e.g. star trackers, sun sensors, and magnetometers) and rocket thrusters to determine and adapt the satellite's orientation.

G. - E. Giataganas

f. Telemetry, Tracking, and Command (TT&C): The TT&C subsystem enables communication between the satellite and the ground segment. It is responsible for transmitting telemetry data about the satellite's health and performance, the monitoring of important parameters (such as altitude, orientation and temperature), receiving commands from ground control, and facilitating tracking of the satellite. In general, it is necessary for the control of satellite's components [22].

g. Communication System: It is vital for the transmission and receipt of signals data between the satellite and the ground station on Earth or other affiliated satellites, through antennas and transponders.

h. Payload: The payload is the valuable equipment and the primary reason for the satellite's existence, as it performs the mission-specific tasks and fulfils the relative purposes and goals. As payload could be considered the sensors, the transmitters – receivers, the communication transponders, the Earth observation instruments (e.g., cameras, spectrometers), the scientific instruments the navigation equipment and other parts – tools that are vital for the mission performance [21].

Ground Segment

The ground segment encompasses all the Earth-based components necessary for controlling, tracking, and operating the satellite system.

a. Ground Stations: Ground stations are installations that communicate with satellites using antennas and tracking equipment. They transmit commands, receive telemetry data, and facilitate data downlink from the satellite's payload.

b. Mission Control Center (MCC): The MCC is responsible for overall satellite system management, including monitoring satellite health, planning and executing commands, and coordinating with other ground stations.

c. Data Processing and Distribution: This involves the processing of raw data received from the satellite into useful information, such as images or navigational data, and distributing it to end-users or other organizations.

d. Tracking and Data Relay Satellite System (TDRSS)⁶: In some cases, a network of relay satellites, such as NASA's TDRSS, is used to facilitate continuous communication between ground stations and satellites in low Earth orbit [21].

Launch segment

The launch segment is a critical part of any space mission, responsible for delivering spacecraft or payloads into orbit or deep space. The main parts of a launch segment can be categorized as follows:

⁶ more information available at article: NASA, Tracking and Data Relay Satellite System (TDRSS), https://www.nasa.gov/directorates/heo/scan/services/networks/txt_tdrs.html

a. **Launch Vehicle:** The launch vehicle is the rocket system responsible for propelling a spacecraft or payload into Space. They come in various types, such as expendable or reusable, and are often multi-staged to maximize efficiency. Some notable examples include the Falcon 9⁷ and Falcon Heavy by SpaceX, the Atlas V⁸ and Delta IV by United Launch Alliance, and the Ariane 5⁹ by the European Space Agency (ESA).

b. **Launch Pad:** The launch pad is the physical structure from which the launch vehicle lifts off. It provides the necessary infrastructure, including fueling systems, electrical connections, and environmental control systems. Some well-known launch pads are Launch Complex 39A at NASA's Kennedy Space Center¹⁰, which has hosted numerous Apollo and Space Shuttle missions, and Baikonur Cosmodrome¹¹ in Kazakhstan, where the first human, Yuri Gagarin, was launched into space.

c. **Ground Support Equipment (GSE):** GSE encompasses all the equipment needed to support the launch vehicle and spacecraft operations at the launch pad. This includes fueling systems, electrical and communications systems, environmental control systems, and safety systems. GSE is essential for vehicle integration, testing, and countdown procedures.

d. **Range Safety and Tracking:** Range safety involves monitoring the launch vehicle's trajectory, weather conditions, and any hazards in the area, such as boats or planes that could be in the vehicle's flight path. Range safety officers have the authority to abort the launch if necessary. Tracking involves radar and telemetry systems to monitor the vehicle's position, velocity, and health during flight.

e. **Launch Control Center (LCC):** The LCC is the command and control hub for launch operations. It houses the launch team, who monitor the launch vehicle, spacecraft, and range safety. The LCC is responsible for managing the countdown and ensuring all systems are "go" for launch.

f. **Mission Control Center (MCC):** The MCC is responsible for managing the spacecraft's operations once it has separated from the launch vehicle. They coordinate with the LCC to ensure a smooth transition from launch to on-orbit operations.

g. **Integration and Testing:** Prior to launch, the spacecraft and launch vehicle must be integrated and tested to ensure they are functioning correctly. This process includes connecting the spacecraft to the launch vehicle, performing various systems checks, and conducting rehearsals of the launch countdown [21].

⁷ more information available at SpaceX - Falcon 9: <https://www.spacex.com/vehicles/falcon-9/>, accessed: 20/02/2023

⁸ more information available at United Launch Alliance - Atlas V: <https://www.ulalaunch.com/rockets/atlas-v>, accessed: 20/02/2023

⁹ more information available at European Space Agency - Ariane 5: https://www.esa.int/Enabling_Support/Space_Transportation/Launch_vehicles/Ariane_5

¹⁰ NASA - Launch Services Program, accessed: 20/02/2023, available: <https://www.nasa.gov/centers/kennedy/launchingrockets/index.html>

¹¹ More information available at Roscosmos - Baikonur Cosmodrome, accessed: 20/02/2023, available: <https://www.roscosmos.ru/25132/>

2.2. Types of satellites

2.2.1 Taxonomy by size

As expected, satellites vary in size, with sometimes the size difference to be small, but other times the difference is really huge. Although size or mass is a common way to classify satellites, it is not the only criterion. Other factors such as their function (communication, Earth observation, technology demonstration, etc.), their orbit (LEO, MEO, GEO Orbit, etc.), or their lifespan could also be used to categorize them.

For instance, some cube satellites are as small as 10 centimeters. Some communication satellites are about 7 meters long and have solar panels that extend another 50 meters. The largest artificial satellite is the International Space Station (ISS). Most of the satellites we are able to see with naked eye on the night sky are smaller satellites in the low-Earth orbit. The GEO satellites are so high/distant from the Surface that are visible only with a powerful telescope.

This classification, which concerns only the size (expressed at mass – kilograms units) of the satellite, is rather informal but widely accepted within the space industry. In addition, due to the lack of definitive universally - accepted categorization, the weight ranges can vary slightly based on the source.

Of course, although size is a way of common sense to classify satellites, definitely is not the only criterion. Other factors such as their function - operational mission, their orbit, or their lifespan could also be used to categorize them.

Below there are presented the following categories, from the smaller satellite to the biggest one:

Small Satellites: Small satellites can be divided to the following subcategories who follow.

Mini Satellites: Satellites in this weight category (100-500 kg) are often utilized for scientific research, Earth observation, and technological demonstration purposes. The relatively low cost and flexibility of mini satellites have made them an attractive option for academic, commercial, and government entities. These platforms have provided a cost-effective solution to test new technologies and conduct space science missions. Mainly, these satellites are in LEO, while most of them are oriented for Earth and solar observation.

Micro Satellites: With a weight range of 10-100 kg, micro satellites are an increasingly popular choice for a variety of applications. Their small size and lightweight design make them cost-effective to build and launch. The trend towards constellations of micro satellites allows for distributed functionality and enhanced coverage capabilities, useful in communication networks and Earth observation systems, and generally on more complicated and demanding missions. The microsatellite usually is deployed in LEO.

Nano Satellites: Nano satellites, such as CubeSats, weigh between 1-10 kg. They have become popular for space research, primarily because they can be produced and launched at a lower cost compared to their larger counterparts. As it is comprised from small size parts and systems, it can perform only specific actions, such as communications, geolocation, monitoring et cetera. The nanosatellite is limited in LEO, while some of them require the “cooperation” with another satellite, to transmit and receive signals to and from ground stations. They are often used by educational institutions and research

organizations for technology demonstrations, scientific research, and educational purposes. [23].

CubeSats: CubeSats are a class of nanosatellites that use a standard size and form factor. The standard CubeSat size is a cubic unit (1U) measuring 10x10x10 centimeters. Except this fundamental size, there are also designed CubeSats to larger sizes such as 1.5, 2, 3, 6, and even 12U. Initially, the CubeSats were designed to provide a platform for education and space exploration. However, after years, governments and enterprises realizing their capabilities, invested at this type of satellites and nowadays CubeSats provide a cost-effective platform for science investigations and new technology demonstrations¹².

Medium Satellites: Satellites in the 500-1000 kg weight range, or medium satellites, represent a balance between payload capacities and launch cost. They are used for a variety of applications, including communication, navigation, meteorology, and Earth observation. Their versatility and balance between capability and cost make them a popular choice for many types of space missions. Regarding their orbits, they are set in LEO, MEO and GEO¹³.

Large Satellites: Large satellites (over 1000 kg) are the traditional satellites used for high-capacity communication, space exploration, and military applications. These satellites often have complex systems and long lifetimes. Large satellites are generally launched by government or large corporate entities due to the substantial cost involved in their construction and launch. The size and capacity of these satellites make them suited for applications that require high power, such as television broadcasting and secure military communications and Earth observation¹⁴. Most of them are in GEO, however the largest artificial satellite is a habitable space laboratory, ISS, orbiting in LEO (approximately 400 kilometers) every 92 minutes.

Quantity	Platform mass, kg
Large spacecraft	≥ 1000
Medium spacecraft	≥ 500 and < 1000
Small spacecraft	< 500
Minispacecraft	≥ 100 and < 500
Microspacecraft	≥ 10 and < 100
Nanospacecraft	≥ 1 and < 10
Picospacecraft	≥ 0.1 and < 1
Femtospacecraft	≤ 0.1

Figure 3: Satellite sizes comparison

[Source: Survey on Guidance Navigation and Control Requirements for Spacecraft Formation-Flying Missions, G. Di Mauro, M. Lawn, and R. Bevilacqua University of Florida, Gainesville, Florida, 2017]

¹² The European Space Agency, CubeSats, available:

https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/CubeSats

¹³ How big is that satellite? A primer on satellite categories, accessed: 20/02/2023, available:

<https://news.viasat.com/blog/scn/how-big-is-that-satellite-a-primer-on-satellite-categories>

¹⁴ Medium and Large Satellite Market, accessed: 20/02/2023, available:

<https://www.transparencymarketresearch.com/medium-large-satellite-space-market.html>

2.2.2 Taxonomy by operation – mission

The numerous orbiting satellites serve different daily operational needs at a different operational level. Even for the same field of interest there is a variety of satellites regarding the size, the features they dispose, the orbit and general their overall function. Below, are presented indicatively the main categories:

Communications Satellite:

This type of satellites was the first to set in orbit since early 60' s. There are three different types of communication services that these satellites provide, such as telecommunications, broadcasting, and data communications. The part of telecommunications deals with all the services that are necessary for the line telephone, mobile and cellular network providers. The most important device that is included in the satellite is the transponder, which is a radio or radar set that receives a signal at a particular frequency and after amplifying it, emits it back to a ground station or to other satellites (for relaying communications signals).

The part of the broadcasting services, at a similar way, provide directly radio and television signals, from one point to another, to the mobile broadcasting services and their subscribers. The part of data communications deals with the transfer of data through the satellites, especially for international organizations or companies that need to traffic their data to different and many locations around the Earth, through the VSAT technology.

Finally, the evolvement of the Internet and the demands of billions users worldwide, led to a big amount of Internet traffic transmitting through satellites. In general, there are over 2000 communication satellites in use, and they can be found in GEO, HEO and LEO. Despite the delay transmission that is noted, especially in the far GEO, a satellite can service uninterruptedly during vast natural disasters, where ground stations are out of order or during critical military operations. There are many types of telecommunication satellites, with designs varying according to their purpose. They use different orbits and frequencies, and they transmit very different types of signals using a variety of power levels. [22]

Weather satellites:

This type of satellite is used for meteorological and circular natural phenomena predictions. Thus, with images and data receiving from these satellites we can evaluate short term weather forecasts (temperatures, rainfalls etc.) or phenomena such as typhoons and hurricanes. In addition, this data, can be very helpful for understanding better the weather patterns, after years of observations, and make more accurate long term weather predictions. The onboard instruments measure the various conditions of the atmosphere, gathering all the necessary data and information.

The huge advantage of a weather satellite is that, while being in orbit, it can cover all the Earth, whereas the ground conventional forecast stations can cover only the 1/5. The most common orbits for this type of satellite are the polar SSO or the GEO. In the first case, the satellite has a low altitude and visits a specific geographical area at a fixed time. Thus, the observation takes place under identical sunlight conditions with an ideal spatial resolution. This orbit is very convenient for the study of clouds, winds etc, however the time coverage

is too low as the satellites pass over the same geographical area from 1 to 4 times per day (depending on the satellite's altitude).

On the contrary, weather satellites in GEO cover an extremely large geographical area (almost half the Earth's surface), constantly. These satellites are used to measure and report the Earth's weather, and the reports are used for weather forecasts. The images can be taken in the visible, infrared and microwave bands. In general, weather satellites provide us with the ability to observe weather on a global scale, allowing them to follow the effects of phenomena like volcanic eruptions and burning gas and oil fields, to the development of large systems like hurricanes and El Niño. [26].

Navigational satellites:

This type of satellite is designed to help operators of cars, ships, airplanes and other vehicles or vessels to identify their geographical position and navigate accurately. The U.S. Navy developed the first operational satellite navigation system – called Transit – in the 1960s. Navigational satellites comprise a global network satellite radio signal transmission, located at the MEO. The majority of people are familiar with the USA's NAVSTAR GPS which is the most prevalent.

The GPS is a constellation of 27 satellites (24 fully operating and 3 spares). Initially, the U.S. military developed this satellite network for the navigational support of military operations, but eventually the last two decades it was distributed publicly. The orbits of the constellation are arranged at a way that at any time, at any place on Earth, there at least four satellites "visible" in the sky. Respectively, there also other navigation satellite systems, such as European Union Galileo (24 fully operating satellites and 6 spare), Russia's GLONASS (24 satellites in orbit), China's BeiDou Navigation Satellite System (35 satellites), India's IRNSS/NavIC (7 satellites in orbit) and Japan's QZSS (4 satellites in orbit).

Collectively, the aforementioned constellations and their augmentations are known as GNSS. All the providers offered for free their navigation systems to the international community. In addition, they developed ICAO (International Civil Aviation Organization) Standards and Recommended Practices to support the use of these constellations for aviation. The GNSS constellations provide signals from space that transmit positioning and timing data to GNSS receivers. The receivers then use this data to determine location [24].

Earth observation satellites:

This type of satellite, known also as remote sensing satellite, are designed for the observation of our planet from Space. They are divided to the satellites that are used strictly for military purposes and to these that are used for non-military purposes, such as environmental monitoring, mapping, meteorology, natural disaster monitoring and others. Most satellites are designed to take satellite images of specific areas of interest. Regarding the civilian use of these satellites, viz the global land – cover observation, the first one was launched in 1972 by USA, and today almost 1000 satellites of these type are operating. In addition, these satellites capture images either with passive or active way. The passive way of image receiving deals with the radiation that is reflected from the Earth's surface, such as visible light and infrared.

On the contrary, on the active way of image receiving, the satellite transmits energy to the Earth and measures the returned signal from the Earth, and afterwards, the analysis of this signal can provide information about the surface. Regarding the type of sensors that take the images, they can be divided in panchromatic, multispectral and SAR sensors [25], depending on the under-study surface and the desired field of study.

Today, the spatial resolution, meaning the measure of the smallest object that can be resolved by the sensor can be categorized to *very high* (0,5 – 4,9 meters), *high* (5 – 9,9 meters), *medium* (10 – 39,9 meters), *moderate* (40 – 249,9 meters) and *low* (250 – 1500 meters). The earth observation satellites, depending on their mission are set at different orbits, providing various perspectives of Earth [26].

Search and Rescue satellites:

This type of satellite is designed to respond to radio distress signals transmitted from vessels at sea and in the air, to interact and communicate at emergency situations, while being at remote areas. The basic function of this satellite is the detection and geolocation of the emergency beacon's signal for the early warning and dispatch of assistance.

The idea of the implementation of search and rescue satellites origins from the weather satellite's operational function and particularly the interchanging information with the ocean buoys. With the use of the Doppler's effect, the satellite could identify the exact buoy's geolocation point. Respectively, rescue satellites use the same technique to receive distress signals that transmit at predefined frequency.

Thus, from the resultant analysis, the signal can be decoded into coordinates, which leads to the geolocation of the distress signal within a four-kilometer range. The newest search and rescue system is the COSPAS - STARSAT system, which is an international search and rescue system made up of a network of satellites in space, and Earth-ground and mission control stations and rescue coordination centers that detects and locates emergency signals [27].

Depending on their operational altitude, the satellites' constellation is distinguished to LEOSAR, GEOSAR and MEOSAR satellites. LEOSAR satellites can detect and geolocate 406 MHz frequency distress signals all over the world. Their operational altitude ranges around 850 kilometers and they complete an orbit every 102 minutes. During their orbit, they store all the received 406 MHz signals and continuously downloads this data for up to 48 hours, to ensure that ground stations will receive it. GEOSAR satellites are not able to geolocate a signal (due to the lack of relative motion), however they can provide immediate alerts. MEOSAR satellites that are the last added value, provide real-time alerting worldwide as well as an enhanced alerting capability, both in time and location accuracy. [28]

Military satellites:

The use of satellites on military operations is undisputed. In fact, to such an extent that anyone can easily perceive the importance of the range of their characteristics and their functional potential. The first satellites of this types were launched at end of 1950s for simple reconnaissance missions, by taking high resolution (for that era) images of the areas of interest. Nowadays, they compose a spectrum of different application areas and

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activities, such as, army forces relaying encrypted communication, nuclear monitoring, observing the enemy movements and bases, early warning of missiles launches, eavesdropping on Earth's surface radio links, radar imaging, imaging, ISR (Intelligence, Surveillance and Reconnaissance), PNT, DEW (Directed Energy Weapons), navigation and geodesic, signal interception, reconnaissance and ocean monitoring, oriented to a defence and counterattack philosophy.

It is indisputable that with the existent advanced technology, a military satellite can play a crucial role either on preceding or ongoing military conflicts, but also in peacetime. One could tell that these satellites are priceless in the modern military operations, as identification, gathering and transmission of vital information and data can happen in real – time, with global coverage. Thus, it is not accidental that all the developed countries use them as an integral component at their military planning. For instance, USA army forces made an extend use of military satellites during the military conflicts in Yugoslavia (1999), Afghanistan (2001) and Iraq (2003) [29].

Below there are presented some of the various types of military satellites.

Reconnaissance satellites:

This type of satellite, known also as spy satellite, is an Earth observation or communications satellite, deployed for military or intelligence applications.

The implementation of these satellites gave the opportunity to the decision makers to have a complete view of the premises or movements of their adversary awe, that otherwise would not have the slightest idea. The measure of effectiveness of a recognition satellite depends on various factors, such as the cover range, the velocity of transmission of information to the ground receiver, the time lapse for passing again over the same observing post etc. However, the most characteristic attribute taking into consideration for the efficiency of a recognition satellite is its resolution. The efficiency of a satellite sensor comes of a set of individual resolutions, such as spatial, spectral, radiometric and temporal resolution.

As spatial resolution is defined the ability of the sensor to distinguish two objects at the study area that are very close to each other. As the spatial resolution increases, more accurate information is extracted from the image processing and analysis. The spatial resolution definitely depends on the properties of the recording medium, but it also depends on the contrast of the recorded object with its environment, meaning that if there is an observing contrast of the object with the surrounding environment, then it can be recorded even if its dimension is less than one pixel.

Definitely, if apart from the increased characteristics of the recording medium and the intense contrast of the recorded object with its environment, we add any existing information, from different areas of the electromagnetic spectrum or even from the same area that have been received at different times in the past in a different way (e.g. ultraviolet, visible and infrared), then we can take advantage of the spectral resolution of a satellite and can extract additional information about an object or even locate another variant.

The radiometric resolution of a satellite refers to the number of different shades of gray that a satellite can display. It is logical to conclude that the higher the brightness levels that a satellite can display, the more accurate the information obtained about the object under observation.

Often, the catalytic factor for drawing safe conclusions when observing an object is the temporal resolution of a satellite. This is the property that is based on the frequency of taking an image, for instance how often a satellite has the ability to "scan" the area in question in order to obtain the requested information about the state of the object and the changes that have occurred in it.

According to their mission and applications, they can be subcategorized to the following three types:

IMINT or photo – surveillance satellites:

They ensure the observation and study of areas with high spatial resolution and accuracy that could not be accessible by any other ways. Their operational purpose deals with the receipt, process and transmission of spatial images regarding the environment and the Earth's surface, by measuring the electromagnetic radiation that is emitted or reflecting from various objects. Such areas could be steady targets, such as military airports, missiles and submarines bases, critical infrastructures, coordinating centers and others.

However, they are not effective at distinguishing persons and moving targets, and of course entities or constructions below Earth's surface [30]. The interesting fact is that a military IMINT satellite provides images with much higher resolution compared to a corresponding civilian satellite. In general, IMINT satellites constitute most of the military satellites. Most likely, they are set to low, near PO at altitudes 350 – 850 kilometers to take the most optimal, clear images, with a spatial resolution of a few centimeters.

Though there are different ways of taking photographs, such as, close - look (which provide high - resolution photographs that are returned to earth via a reentry capsule), area - survey (which provide lower - resolution photographs that are transmitted to earth via radio), hybrid (combination of the two preceding ways), radar (which provide images of enemy activity when there are dense clouds or observation at night) and electro - optically (which provide photographs in visible light and infrared, can depict heat sources during the night, but are operational only at clear sky) [31].

SIGINT satellites:

The signal interception satellites' contribution at some cases is more valuable from image satellites, due to the quantity and the quality of the data that they provide. Usually, these satellites are set in GEO, where they can cover a huge amount of the Earth surface and record all the types of wireless telecommunication. They can perform various interceptions, such as COMINT (Communications Intelligence), where this term refers to the gathering and decryption of diplomatic, commercial, political, and military communications, transmitted by radio, for the reveal of the message's content. ELINT (Electronic Intelligence) refers to the interception of electromagnetic radiation, which after proper analysis can provide information about the identification and geolocation of enemy bases, vessels, radars, defence systems and early warning stations. TELINT (Telemetry Intelligence) deals with the interception of signals originating from enemy's equipment, such as a ballistic missile. Test. For instance, it can be acquired information about the fuel

consumption of a missile, the velocity and other technical details that permit the intercepting side to evaluate the military status and tactical readiness of the enemy [30].

Early warning satellites:

These satellites are set as well in GEO. They provide timely information on the launch of missiles, military aircrafts, and nuclear explosions. Through their infrared sensors they can detect launches of ICBM, as at a first stage of a missile launch there is huge emission of infrared radiation. In case of a missile launch and after the record of the infrared radiation, the data are crosschecked and compared with already known missiles' traces. Thus, after this process it is known the type of the missile and combined with its technical characteristics, the impact point can be evaluated very accurately. Meanwhile, this procedure ensures the under-attack side about 30 minute's early warning that can be vital for a proper reaction.

Mission	Number of Satellites
Communications	3135
Earth Observation	1052
Technology Development	383
Navigation	154
Space Science	108

Figure 4: Satellites by their most common mission (as by May 2023)

[Source: <https://nanoavionics.com/blog/how-many-satellites-are-in-space/>]

2.3 Satellites importance in sectors of defence and security

Apart from all the types of satellites and their operating missions, defence and security consist two of the most important and investing sectors of each country that has a developed or developing presence and interest in the Space industry.

Thus, the primary purpose with the operational use of earth observation satellites is to strengthen a country's foreign and defence policy, which is firstly achieved through the timely and valid observation of events that take place in other states and that are likely to affect international balances in general and national interests.

A timely and correct awareness and update on actions that could jeopardize national sovereignty or even the sovereign rights of a state are the key into developing the appropriate response tools to mitigate any risk and take the best possible - operationally and strategic - decision.

However, the contribution of Earth observation satellites is not limited at this point. Reconnaissance satellites, as already mentioned, offer an unprecedented comparative advantage to their users, as the latter can know the strengths and weaknesses of their enemy defence, the location and structure of their control and command centers, the bases of their missiles, their telecommunication centers, their military movements, the order and strength of their forces, and any other specific action they take in preparation for a possible armed conflict.

As a result, they have the time and clarity to avoid the sudden movements of their opponents, but also to develop all the specific sets of countermeasures that are necessary to protect them. Rather, they themselves, having the upper hand in the field of information, can achieve a surprise attack against the awe-inspiring enemy, making the best possible choice of the number, type and armament of the aircraft that will attack a target.

In any case, no one can ignore the fact that Earth observation satellites generally contribute to the prevention, monitoring, but also response to crises, in the sense of detecting events that prescribe the least tension in a wider area, and the more even the start of a war. The existence of a crisis can be considered to exist even in the event of a breach of armaments agreements. Thus, Earth observation satellites offer significant support to the successful outcome of peacekeeping missions, but also to the monitoring of disarmament agreements on the existence and maintenance of disarmament zones.

On the other hand, the information and data transmitted by Earth observation satellites contribute to the enhancement of transparency and the development of relations of trust between the various states, and often with the help of diplomatic channels, and any disputes that may arise in the relations between the states are resolved. It is an indisputable contribution of reconnaissance satellites based on the dissemination of information regarding the exact location and image of fixed targets of various states, such as important facilities of strategic interest, as well as defence military equipment that has been advocated for their protection.

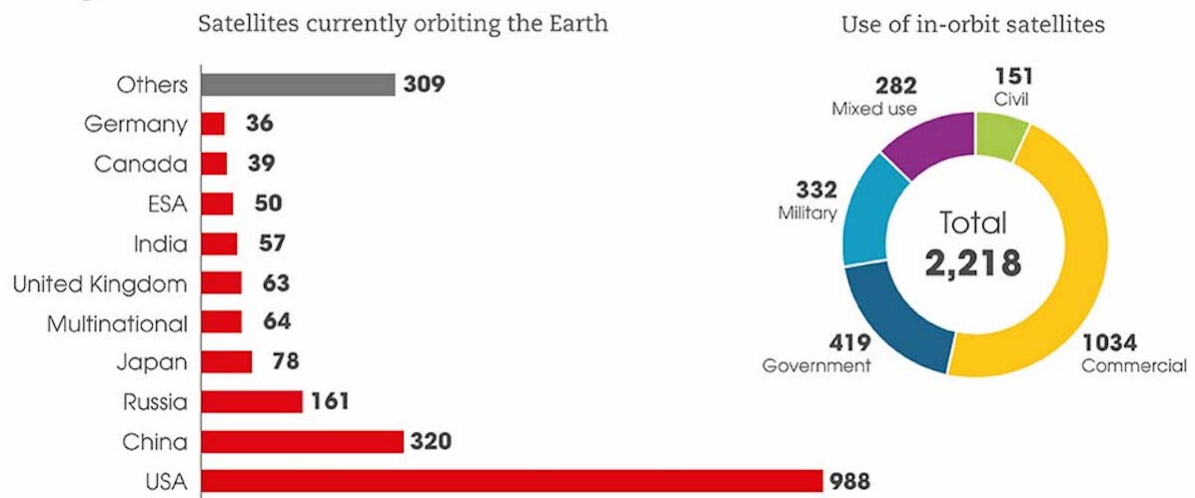
Of course, in locating fixed targets, the recording of troop movements, the detection of new weapons systems, but also the recognition of their specific characteristics is added, resulting in the creation of a list of military targets that is constantly keep updating.

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In addition to building relationships of mutual trust, a peculiar relationship of mutual deterrence is created. The two sides, through the images they receive from their satellites, know that there is the possibility of retaliation from any of their aggressive actions, with the result that this fact acts as a deterrent to their declaration of hostilities. Peace is maintained, the sense of security and stability is consolidated, social, economic, and cultural life develops and evolves.



Satellites in space



Source: Union of Concerned Scientist Satellite Database (October 2019)

Image 10: Use of in-orbit satellites for year 2019

Source: <https://www.iybssd2022.org/en/satellites-for-development-facts-and-figures/>

PART B. SECURITY FROM SPACE

The last years, more and more satellites have been deployed in the Space, to support daily civilian, commercial and governmental activities. Traditionally, the support of the security and the defence from the Space is considered a strongly bind with the support of military and security forces at an intelligence, operational and strategical level [32].

It is highly undisputed that in many cases, the involvement of satellites has had an important role in huge crisis or military conflicts, making it clear that space could be considered an independent operational sector. In fact, on December 2019, the NATO with the London Declaration has declared the Space as the fifth operational sector¹⁵, recognizing its importance in keeping us safe and tackling security challenges, while upholding international law.

Thus, it is internationally accepted that, nowadays, operations can simultaneously take place in land, aviation, maritime, cyberspace and space, making the strategic and operational plans and tactics as well highly complex. At the same time, not only the army forces, but also security forces and other governmental or humanitarian organizations could be a part of the operations during a crisis. For this reason, the modern crisis management employs all the available media, on the field and off the field with the panoptic view that Space offers.

From the Space Sector aspect, the space power holds a fundamental key role at military operations. Nowadays, the space systems are more and more necessary at the preservation of a satisfactory defence level of all countries, especially after the reduction and restructuring of the Military Forces that is taking place from the countries after the post-cold war era. The most notable difference between the military and the civilian satellites is that the military satellites belong exclusively to their operating countries and unless prior authorization from the country, no other government or organization can have access to them. In a daily routine, some hundreds satellites are occupied for military operations that are oriented but not limited to reconnaissance – intelligence gathering, early warning for imminent hostile attacks, telecommunications, navigation, weather prediction, mapping, target surveillance and more[26].

Regarding the civilian use of the satellites, modern governments and organizations have taken the opportunity to observe from distance (at least 300 kilometers above the surface) critical aspects of our planet, such as the circulation of atmosphere, the fauna, the flora, the oceans and in general the natural environment. Also the uninterrupted incoming data stream permits the constant study and the record of important indexes, while it has been so far proved valuable ally and will continue to be at humanitarian, safety and rescue missions [26].

¹⁵ London Declaration, issued by the Heads of State and Government participating in the meeting of the North Atlantic Council in London 3-4 December 2019, NATO, 4 December 2019, https://www.nato.int/cps/en/natohq/official_texts_171584.htm#utm_source=twitter&utm_medium=natosg&utm_campaign=191204%2Bmeeting

3. Use of satellites for Defence purposes

3.1. Reconnaissance - Intelligence gathering

The strength of the information is prevailing, especially in our modern era, where all the aspects of daily social and economic life is flourishing. Thus, the data are being increased and getting more and more complex than ever, leading us to employ new ways in order to gather, process and analyze them. Subsequently, the same situation deals with the intelligence oriented to defence purposes.

More specifically, the use of reconnaissance satellite has started since the early 1960s from both the U.S.A. and the former Soviet Union. Thus, it is not surprising that the constant information and gathering of data are of the highest values nowadays. The situation is quite simple. Whosoever has the information, has the advantage as he is benefited by the element of the situation awareness and surprise.

Of course, it is very vital for army and secret services to have at their availability satellites of this kind, in order to have all the necessary information from the sky at a rapid and precise way. Therefore, it makes sense that the most important and more widely known satellites oriented to reconnaissance and intelligence gathering had been employed by the Army Forces. Obviously, these satellites are equipped with high tech instruments, such as image and video recording devices, multispectral scanners, radars and other devices of high sensitivity, designed for these special missions.

It is not difficult to imagine the decisive advantage from tactical and operational aspect, a high resolution satellite image provides to a military force. This well-known type of satellite is used to collect images of the global surface, including terrains, infrastructures, and last but not least, military assets. These images usually are used for tracking major or minor changes in enemy activity, identifying potential targets, and assessing the effectiveness of military operations.

For instance, depending of course on the operational function and satellite's technical attributes, an interested party could receive crucial information. More specifically, such satellite images could depict at their operational area fixed goals such as airports, missile and submarine bases, early warning stations, troops gathering and other valuable information at real time.

Until two decades ago, the main actors of constructing and using such satellites, had been USA, Russia, Israel, France and China¹⁶. But nowadays, the situation has been radically changed and it is worth noting that the number of countries with satellites is at least 27¹⁷. This number is going to be constantly changing as new countries enter this space domain and as well the number of the launched satellites, as our era is getting more and more competitive at all the sectors. It is worth noting that, at least until the last three years the number of spy satellites owned only by governments, estimated to be from 339 to 485 satellites. This number seems to make sense since the 20% of all satellites (a well-respected percentage) are launched for military operations¹⁸.

¹⁶ Alexandros K. Kolovos, Space and National Security: Political and Strategical Dimension, Poitita, 2003, pp. 122

¹⁷ This Is the Country With the Most Military Satellites, Samuel Stebbins, accessed: 15/04/2023, available: <https://247wallst.com/special-report/2022/04/21/this-is-the-country-with-the-most-military-satellites/2/>

¹⁸ Modern spy satellites in an age of space wars, Zulfikar Abbany, 08/25/2020, accessed: 15/04/2023, available:

<https://www.dw.com/en/modern-spy-satellites-in-an-age-of-space-wars/a-54691887>

But who were they the first of the satellites that had been used for tactical and operational intelligence? Three decades and more ago, even before the famous Google Earth existed, a top secret satellite program had been launched, with code name Hexagon, although the intelligence community called this with the names “Big Bird” and “Keyhole 9”. It is really remarkable the fact that Perkin-Elmer, top engineer at the company that designed and built the Hexagon’s camera, mentioned emphatically the following: “I honestly think that the Hexagon program was responsible for preventing World War III”¹⁹, meaning that the satellite gave the opportunity to the USA intelligence services to have a constant “eye” on Soviet troops, tanks, aircrafts, missiles and other military material. At that era, the distinctive ability of Hexagon satellite was to the impressing approximate 60 centimeters.

Thus, the USA has been using the reconnaissance satellite with the code name Kennen “Keyhole-class” (KH) for at least the last 30 years²⁰. This type of satellite is being orbited at an altitude ranging from 150 to 500 kilometers from the Earth’s surface, transmits digitally the images to the ground center, with a remarkable distinctive ability of 3 to 5 centimeters, meaning that any object with size more than 3 to 5 centimeters can be distinctively observed from this huge height, when the satellite’s lens is open. One really interesting feature is that the lens can be turned sideways, giving the opportunity for the monitoring of a larger area. However, this exceptionally high distinctive ability presents a main drawback that leads to a limited field of view ranging from 10 to 100 kilometers [33]. The most recent model KH-12 worths 1 billion dollars and many people parallel this with the Hubble Space Telescope, however the latter observes in the opposite direction (deep Space). KH satellite contains an enormous digital camera for receiving images, by using a CCD [34].

Finally, Russia uses reconnaissance satellites with code name Cosmos that have similar distinctive ability with these of USA. Following, Israel, France cooperating in a small degree with coalition Italy-Spain and China have also launched reconnaissance satellites with distinctive ability of 1 meter [26].

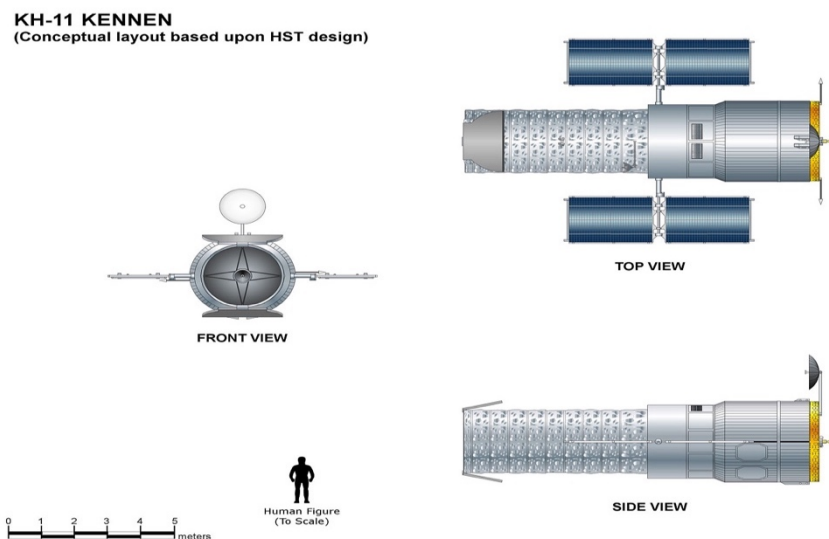


Image 11: KH-11 KENNEN

[source: https://en.wikipedia.org/wiki/KH-11_KENNEN#/media/File:KH-11_KENNEN_01.jpg]

¹⁹ 1970s spy satellite 'better than Google Earth', Thom Patterson, 01/09/2016, accessed: 15/04/2023, available: <https://edition.cnn.com/2016/09/01/us/declassified-spy-satellite-hexagon/index.html>

²⁰ What is a keyhole satellite and what can it really spy on?, accessed: 15/04/2023, available: <https://science.howstuffworks.com/transport/flight/classic/jets-and-rocket-xflight.htm>

3.2. Early warning

Satellites play a crucial role in modern defence, especially in military early warning systems. These systems are designed to detect and notify defence authorities of potential threats, security concerns, and other critical events, by providing timely and accurate information.

From tracking missile launches to monitoring troop movements, early warning satellites offer a vantage point from Space that enhances military capabilities and enables nations to respond effectively to various security challenges. These satellites, orbiting the Earth, are equipped with advanced sensors that can detect and analyze various indicators, helping the interested parties to respond proactively (by initiating diplomacy route) and actively (by deploying countermeasures) to impending risks.

The applications of early warning satellites are referred indicatively but not limed to the following categories:

➤ **Space-Based Infrared System (SBIRS)**

This is system that has replaced Ballistic Missile Early Warning System (BMEWS) of the U.S.A. Defence Support Program (DSP) after decades of successful and satisfactory operation. Satellites were orbiting in GSO and LEO and they were equipped with sensors, primarily infrared, to detect sudden large amounts of heat²¹ that are generated by ICBM missile launches. Furthermore, once a missile's launch was detected, its trajectory was predicted to quickly determine if it posed a threat.

SBIRS is an advanced early warning system that is the successor of BMEWS since 2011. Its primary purpose is to enhance the overall mission of BMEWS, by providing early warning of ballistic missile launches and supporting other missions like missile defence, technical intelligence, and battlespace awareness. The components of SBIRS are being comprised by HEO payloads and GEO satellites. In the first case, it is about sensor payloads that are attached to satellites in HEO, while in the latter case, satellites orbiting in GSO carry scanning and staring sensors to detect and track missile launches [35].

Compared to the BMEWS, SBIRS brings significant improvements to the following features:

- Enhanced sensor flexibility allows for improved scanning and staring operations.
- Increased sensitivity of sensors helps in detecting shorter-range, tactical missiles.
- Advanced data processing capabilities mean faster detection and reporting times²².

It is worth noting all the recorded satellite data regarding an ICBM launch are transmitted to high performance computer systems that compare instantly the under examination produced heat “traces” with other confirmed ICBM heat “traces” that are stored in a relevant database. This process has a double meaning, on the one hand it is crosschecked in real

²¹ When a missile is launched, combustion gases are generated, which consist mainly of the combustion products of the fuel (primarily carbon dioxide and water vapor). The molecules of these substances emit intense energy with a wavelength of 2.7 microns. See Alexandros K. Kolovos, *Space and National Security: Political and Strategical Dimension*, Poiotita, 2003, pp. 125

²² More information can be found in the website of Missile Defence Advocacy Alliance, <https://missiledefenceadvocacy.org/?s=SBIRS>

time if a missile attack is under progress, and on the other, in a positive case, the trace “reveals” the type of the missile and its technical specifications, as well the impact area (as much approximately as possible). In numbers, that means that the early warning offers a respond time of approximately 30 minutes [31].

➤ **Nuclear Detonation (NUDET) Detection**

During the Cold War era, with the increasing number of nuclear-armed nations, the ability to detect clandestine nuclear tests became crucial for maintaining international security. For this reason, USA, had already launched since 1963 satellites with the code name VELA Hotel which were replaced later with the satellites NAVSTAR/GPS²³.

The Nuclear Detonation (NUDET) Detection System (NDS) provides a real time and worldwide capability of detecting, locating, and reporting any nuclear explosion inside or outside the Earth's atmosphere, even at near Space or deep Space. The NDS consists of space, control, and user equipment segments [36].

Thus, satellites such as the Global Positioning System (GPS) satellites carry sensors to detect the optical and electromagnetic pulses produced by nuclear detonations. This capability is not just about early warning but also serves as a deterrent, ensuring adherence to international nuclear test ban treaties.

Nuclear detonations emit unique signatures in the form of electromagnetic pulses, light, and other forms of radiation. The NUDET system comprises sensors placed on satellites to detect these signatures [26]:

- **Electromagnetic Pulse (EMP) and gamma ray sensors:** A nuclear explosion emits huge amounts of a highly active form of gamma (γ) radiation. Indicatively, a gamma ray has energy 1.000.000 times larger than the visible light energy. One of the most significant phenomena that create the gamma ray is the EMP.
- **Optical Sensors:** Detect the flash of light from a nuclear explosion. Inside the Earth's atmosphere, the extreme heated gas emits visible light. The shock wave causes the phenomenon of double flash of light, which is the most tangible evidence of a nuclear explosion.
- **X-ray Sensors:** Measure the radiation emitted from a detonation. A nuclear explosion creates extremely huge temperatures (at least 10.000.000 °C) and X radiation, which is from 1.000 to 100.000 larger than this of the visible light.

²³ See Alexandros K. Kolovos, Space and National Security: Political and Strategical Dimension, Poiotita, 2003, pp. 127

➤ **Space Situational Awareness (SSA) and Space Domain Awareness (SDA)**

It is easily understood that since the first man ship launch, tens of thousands of objects in Earth orbit that pose a potential threat to satellites and launches. SSA refers to the constant monitoring of artificial objects in orbit and the calculation of their orbit at any time [37], prediction of their future movement and understanding potential threats.

More specifically, satellites provide the capability to monitor the launch of adversary satellites, their maneuvers, and any possible anti-satellite (ASAT) weapon tests. The SSA is essential to ensure that assets in Space are protected and also to predict potential threats from earth or space-based platforms.

With the increasing existence of more and more satellites in orbit, the task of tracking thousands of objects in Space is getting more and more challenging. The U.S.'s Space Surveillance Network (SSN) assists in this, with its data being critical for both civil and defence activities [38].

From military perception, SSA is performed in order to ensure the following features:

- **Asset Protection:** military satellites, which provide crucial services like communications, navigation (like GPS), and reconnaissance, need protection from potential threats, including adversarial anti-satellite (ASAT) weapons and space debris.
- **Collision Avoidance:** with the growing number of objects in space, the risk of accidental collisions increases. SSA helps militaries avoid potential collisions that could render critical satellites non-functional.
- **Threat Assessment:** SSA helps in detecting potential adversarial activities in space, including the deployment or maneuver of ASAT weapons or spy satellites.
- **Launch Detection:** ground-based missile launches, especially ICBMs, are detected using satellites. SSA ensures these satellites are functional and can provide early warning.

While SSA has traditionally been about tracking and predicting the movement of objects in space, SDA represents a more holistic understanding. SDA encompasses not just positional data but also the intent, capability, and health of satellites, especially potential adversarial ones, profiling and categorizing in this way all the interested artificial objects.

3.3. Command and control

Command and control play a vital role in time of peace, but also especially in an armed conflict or in an incident escalation. Basically, the adversaries' interested parties always need and want to know as much information they can retrieve about the equipment, the movement and the intentions of the other part, in order to adapt their next moves and strategy, almost like playing a chess game.

So, command and control (C2) is a "set of organizational and technical attributes and processes ... [that] employs human, physical, and information resources to solve problems and accomplish missions" to achieve the goals of an organization or enterprise²⁴. In its broadest definition, C2 refers to the process or function of commanding and controlling units of armed forces (or even civilian units) in a theatre of operation.

Towards the achievement of this direction, command and control have to deal with a set of functions that aim to collect, process and transmit information related to the field of combat or the field of geopolitical interest, along with the decision making and its transmission [26]. Of course, all these functions make even more sense at a military operation, where there is need for a well combined set of parameters in order the operation to be considered successful.

More specifically, at this neuralgic domain, satellites play a pivotal role in modern C2 military operations, as the major parts of a C2 system are comprised of early warning systems, information gathering and distribution systems and of course the respective communication parts that link all the involved systems at sea, land and space. All this are of course necessary for the monitoring and the decision making both at times of peace but also during military operations.

So, below follows a typical high level overview of how a C2 system²⁵ is performed with the use of military satellites:

- Ground Stations: these are physical locations equipped with antennas and communication equipment to interface with satellites in orbit.
- Communication links:
 - Uplink: from ground to satellite, used to send commands.
 - Downlink: from satellite to ground, used to receive data.
- Data Processing Centers: facilities where data received from satellites is processed, stored, and analyzed.
- Command and Control Software: provides an interface for operators to send commands to satellites and receive data. This software might offer features like:
 - tracking satellite health and status
 - planning and execution of satellite maneuvers
 - scheduling of satellite tasks and missions
 - automated alert systems for anomalies
- Human Operators: Trained personnel who monitor the health and status of the satellite, intervene in case of anomalies, and execute planned missions or tasks.

²⁴ This is a definition given by Vassiliou, Marius, David S. Alberts, and Jonathan R. Agre in their book, titled: *C2 Re-Envisioned: the Future of the Enterprise*. CRC Press; New York; p. 1, 2015

²⁵ More information available at: <https://www.losangeles.spaceforce.mil/>

- **Security Infrastructure:** due to the critical nature of military satellites, a strong security apparatus is essential. This includes:
 - physical security of ground facilities
 - cybersecurity measures to prevent hacking or unauthorized access
 - encrypted communication links
- **Network Infrastructure:** allows various components of the C2 system to communicate with each other. This might include dedicated communication lines, routers, switches, and other networking equipment.
- **Redundancy and Backup:** given the critical nature of these systems, it's common to have backup ground stations, data centers, and communication links to ensure continuous operation even in case of failures or attacks.
- **Integration with Other Systems:** a military satellite C2 system might be integrated with other defence systems such as missile defence radars, military communication networks, intelligence systems, etc.
- **Support and Maintenance Infrastructure:** this ensures that the entire system remains operational and up-to-date. It includes facilities for repairing and maintaining equipment, as well as training facilities for operators.
- **Environmental Monitoring:** to predict and understand the impact of space weather (e.g., solar flares) on satellite operations, it's common to integrate environmental monitoring into C2 systems [39].
- **Decision-making Tools:** advanced analytical tools and software that assist operators and decision-makers in understanding the tactical and strategic implications of the data received from satellites [40].



Figure 5: U.S. military command & control space architecture

Source: [<https://spacenews.com/u-s-military-space-architecture-to-bring-in-commercial-systems-small-satellites/>]

3.4. Targeting accuracy

Targeting and accuracy, when referring to an armed conflict is maybe the most important element, after the communications between the personnel of the armed forces of course. It is quite understandable that during a war conflict or incident, the identification of the target and its successful neutralization is of the highest values, as many resources are committed towards this direction and in most cases the result can change dramatically without these details.

Even in ancient times, military forces used the available tools for navigation and targeting accurately, such as compasses and sextants in order to pinpoint their target. Since then, many things have changed, including the significant rise of science and technology, which has led to the development of orbiting satellites equipped with extremely accurate and advanced instruments and tools.

For instance, one of the most brilliant examples of the targeting accuracy performed during a wide range war, was in the Gulf War, from August 1990 until February 1991. The breakthrough in this war had to do with the fact that the United States led coalition Forces to launch the first "Space War"²⁶, as a vigorous response at the Iraq invasion to Kuwait. Of course, this is referred to the use of satellite - based global positioning system, as in different case, the navigation, the communication and the guidance of the machinery and all the war equipment through the dessert landscape of Iraq and Kuwait would be extremely difficult.

In general, nowadays, the modern military systems have been significantly improved with the use of GNSS for operational use. For instance, the accuracy provided to aircraft and shipboard navigations systems, permits them to follow more efficient direct flight paths and direct routes/channels. More specifically, the greater achieved accuracy of the three-dimensional plane and velocity permits the flight of equipped airplanes to no-fly zones or safety dangerous points. Regarding the ships, specific GPS receivers have been integrated into a bridge system, where the navy can watch in real time the exact location of companion ships on a digital nautical chart, presenting in this way the overall picture of the theatre of operations [41].

Similarly, improvements have been carried out in missile guidance systems as well. For instance, Tomahawk Land Attack Missile (TLAM), have improved their accuracy strike with the use of GPS receivers²⁷. The updated versions can provide accuracy to featureless terrains and aqua areas, and of course there have become more effective at night and in bad weather conditions. TLAMs, as well updated with GPS, HARMs (High-Speed-Anti-Radiation Missile) and SLAMs (Standoff Land Attack Missile) missiles were launched by NATO forces against Bosnian Serb targets in September 1995 [42].

Following, the U.S. military made many technological innovations at weapons based on GPS, such as precision guide missiles (PGM) which were used during the Operation Desert and performed the majority of target kills [43], a GPS - guided artillery round with drag and steering controls [44] and constantly since then many weapons had been manufactured with increased targeting ability and accuracy from a greater distance.

²⁶ GPS and the World's First "Space War", accessed 01/05/2023, available: <https://www.scientificamerican.com/article/gps-and-the-world-s-first-space-war/>

²⁷ More than 288 TLAM missiles had been used for first time in the Gulf War, R. Holzer, Pentagon Tests Tomahawk Block III Technologies, Defence News, February 25, 1991, p.45
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Overall, satellites are extremely useful for navigation and are even a prerequisite for military operations. The fact that satellite data can provide military forces with intelligence about the location of their adversaries is remarkable. This capability allows for safe navigation through hostile and unknown territories and enables the detection of changes in the terrain, thereby allowing for adjustments to a safer route.

Furthermore, the ability to identify targets from large distances is another benefit achieved through the operational use of satellites, which are not limited by time of day or weather conditions. Additionally, something that might not be possible with traditional physical observation is the use of satellites equipped with advanced surveillance capabilities that share information with ground stations in real time. The use of satellites is both convenient for military forces and presents a significantly lower risk.

Satellites will continue to play an important role in military operations for years to come, as military systems are increasingly oriented towards GNSS for communication, C2, navigation, and PGM launching. Considering that technology continues to evolve, military forces will be able to fulfill their goals and strategic-operational missions with higher success rates.

However, despite the almost perfect accuracy described above, one vulnerability inherent in the space-based nature of satellite systems should be mentioned. The distance - apart from being an ally - can sometimes become an adversary. Normally, the satellite and the receiver are separated by thousands of kilometers, a considerable distance compared to other commercial surface radio signals, which cover a few hundred kilometers at most and are stronger than satellite signals. Consequently, jamming can be performed to 'pollute' the frequency band used by GNSS and block reception. The most inconvenient fact is that this jamming can be carried out using widely available low-cost jammers that interfere with commercial applications [45].

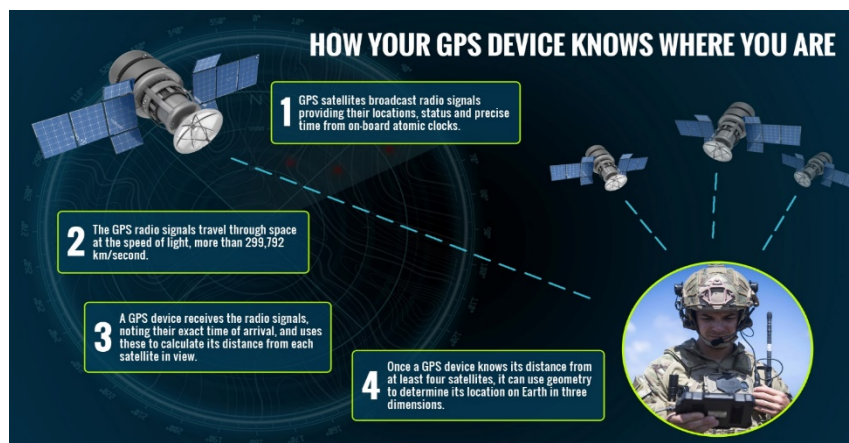


Image 12: How GPS knows our position

[source: <https://www.defence.gov/News/Feature-Stories/story/Article/1674004/what-on-earth-is-the-global-positioning-system/>]

3.5. Espionage

As has been mentioned repeatedly so far, the information about an adversary is of the highest importance. Indeed, spy satellites have become a necessary tool for governments and military forces, as spying constantly and distantly from Space makes it harder to engage in surprise military attacks and invade to other countries successfully. Thanks to this, real time information flow, Space reconnaissance appears to have contributed to increased international stability and peace.

But when was the origin of the first spy satellite? Back in 1954, the Technical Capabilities Panel (TCP) was created with U.S. President Eisenhower's initiative, aiming to design technological alternatives regarding the collection of intelligence dealing with the former USSR and a potential sudden nuclear attack from its side. In early 1955, the TCP appeared with a solution, with code name WS-117L [46]. This turned to be the first attempt for a reconnaissance satellite system, however the project was too ambitious and finally failed.

In 1958, following the successful launches and orbital flights of Sputnik-1 and Explorer-1, the initiative to design a spy satellite was rekindled with the start of the code-named Corona program, which introduced the first KH satellites. The first satellite of this era was equipped with an f/5.0 aperture and a 61 cm focal length panoramic camera, allowing it to take photos of the Earth's surface from space. The Corona Program ended in 1972, after 16 years of operation, and still comprised classified information in the USA.

Reaching to today, the era of information and big data, spy satellites undoubtedly are part of human life, especially when it comes to defence, security and military operations. As it makes sense, for obvious reasons, the spy satellites constitute top secret information for all countries. All know that their function is to orbit over areas of strategic and operational interest, however no one knows exactly how complex is their design and technology as well their special characteristics.

In general, spy satellites have extremely high capabilities. They have state of the art sensors, for collecting various data from the Earth. These sensors consist of cameras, radars and other high sensitive tools, that after receiving all the valuable data, they transmit it at real time at the ground stations for collecting and further processing from the interested parties.

Of course, the most notable and common type of spy satellite is the imaging satellite, which is charged with the task of taking high-resolution photos. These images are analyzed afterwards for up-to-date intelligence, troop's movement monitoring, mapping new areas of interest etc. [47]

Still, there are also other useful kinds of spy satellite, such as signal intelligence satellites, that "eavesdrop" communications and track movements of foreign military or governmental forces, communication intelligence satellites that can be used for jamming and disrupting communications that origin or direct to adversary's satellites and other satellites, oriented to weather forecasting, nuclear weapons detection etc. [48]

Furthermore, according to the designated mission and the optimization of the surveillance capabilities, orbits of the spy satellites vary. Thus, in many cases spy satellites can be set

in LEO, GEO or GSO²⁸. However, the extremely elliptical orbit Molniya is ideal for spy satellites as they can be kept the Northern Hemisphere in view 12 hours a day. That is of course important, because most of the key geo-political players are operating in that area [49]. The selection of the orbit though, is depending on other factors too, such as fuel consumption, radiation exposure, and potential interference with other satellites or space activities. In many cases, the orbit must be changed with specific maneuvers to optimize coverage areas or to avoid collisions with other artificial orbiting objects. Additionally, maneuvers can be performed to enhance the mission of a satellite or to mitigate the risk of an adversary's eavesdropping.

Finally, the information and the data that the spy satellites capture are top secret and very vital for a nation's defence and security. Thus, encryption procedures and secure communication channels are put into operation to protect the transmission of between the satellite and the ground stations and stand against cyber-attacks by adversaries targeting to unauthorized access to the satellite's database [50]. Moreover, many spy satellites use AI and sophisticated onboard processing systems to analyze, filter and sort the captures images before their transmission to the station groups. There, by with the use of machine learning, it is feasible the new images to be compared with an existing image database, resulting to the identification of possible changes (e.g. a new structure being built)²⁹.

Few images have been publicly released that are attributed to military satellite imagery. One of these few examples is included in a tweet (at X platform – then Twitter) by former US President Trump on August 30, 2019 (you can see it right below). This was in reference to an accident at Iran's Imam Khomeini Space Center, where a failed rocket launch was recorded. The tweet was accompanied by a satellite image, unprecedentedly high resolution (compared to what was commercially available. Analysts believed it came from a classified image that was included in the US President's Daily Briefing. Donald Trump told reporters: "We had a photo that I released, I have the absolute right to do." [31]

²⁸ in a geosynchronous orbit, spy satellites are able to record data and images from anywhere on the planet, often on a near-real-time basis

²⁹ Artificial Intelligence & Satellites, accessed: 01/06/2023, available:

<https://www.defenceone.com/insights/cards/space-based-c4isr/2/?oref=d1-cards-continue>

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Image 13: satellite photo over Iranian launch pad

[source: <https://www.npr.org/2022/11/18/1137474748/trump-tweeted-an-image-from-a-spy-satellite-declassified-document-shows>]

3.6. Military communication

One of the very first use of the satellites was for trustable and secure military communications [military satellite communications (MILSATCOM)]. Nowadays, it is appreciated that more than 80% of the U.S.A. armed forces are taking place through satellites, including communication between satellites, aircrafts, naval vessels, terrestrial vehicles and deployed troops. Undisputedly, communications are the most vital point for every operational and tactical C2 center [51].

Thus, it is essential for military forces to have high-quality and seamless MILSATCOM (Military Satellite Communications) to carry out their missions and achieve their objectives. In addition to this, telecommunications and their mechanisms are becoming increasingly demanding, as military operations carried out around the world need to be supported by interoperable systems and a high-speed, stable communications network [52].

Satellites provide efficient and stable capabilities for telecommunications. Some countries, such as the USA, in addition to their military satellites, lease broadband services from private microsatellite clusters for faster communications and lower latency [53]. Efforts are also being made through telecommunications satellites to link various individual systems, such as fighter aircraft with missile defense networks like the PAC-3, as well as other weapon systems with similar capabilities. The modern trend, at least at the announcement level, is for all media to be able to communicate with each other, although implementation is understandably more challenging [54].

The military uses a variety of communications satellites, including those used solely for military purposes, those used for government communications, and even civilian communications satellites and satellite communication (SATCOM) services. SATCOM typically runs using some specific frequencies reserved by the International Telecommunication Union (ITU). Very high frequency, C, S, L, X, Ku, and Ka bands all include sub bands used for SATCOM.

Government and military satellite communications systems in the United States and in some other countries use the X-band and, to a limited extent, the Ka-band. The X-band, with an uplink range of 7.90 to 8.40 GHz and a downlink range of 7.25 to 7.75 GHz, is widely used for long-range military communications, as is the commercial-based C-band. In very special cases, the Ka band is used because very narrow spot beams can be transmitted to and from the satellite. The US government also purchased Ka-band satellites for military use [55].

Nevertheless, there is no single wavelength band that meets all of SATCOM's requirements. All have advantages and disadvantages. Some can support heavy traffic loads, while others are vulnerable to the elements. Some work well in bad weather, but they only provide narrowband communication. Some bands may require larger antennas, but this is ideal for static terrestrial applications. Smaller antennas suitable for aircraft may also be used. The ITU (International Telecommunication Union) has designated the X-band SATCOM frequencies for military use only. However, as this band becomes increasingly congested, MILSATCOM is adopting other wavelength bands [56].

Radiofrequency Bands

BAND NAME			FREQUENCY (ITU)	COMMON USES	
ITU	NATO**	IEEE***		Space	Ground
Very High Frequency (FHV)	A Band (0-250 MHz)	VHF	30-300 MHz	Satellite uplinks	Analog TV
Ultra High Frequency (UHF)	B Band (250-500 MHz)	UHF (300-1000 MHz)	300-3,000 MHz	Mobile satellite services, satellite navigation signals	Analog TV, 2-way radio, cordless phones, Wi-Fi, Bluetooth, mobile phones
	C Band (500-1,000 MHz)	L Band (1-2 GHz) S Band (2-3 GHz)			
Super High Frequency (SHF)		S Band (3-4GHz)	3-30 GHz	Fixed satellite services, broadcast satellite services, satellite uplinks and downlinks	Weather radar, amateur radio, imaging radar, air traffic control
	F Band (3-4 GHz)	C Band (4-8 GHz)			
	G Band (4-6 GHz)	X Band (8-12 GHz)			
	H Band (6-8 GHz)	Ku Band (12-18 GHz)			
	I (8-10 GHz)	K Band (18-27 GHz)			
	J (10-20 GHz)	Ka Band (26.5-40 GHz)			
K Band (20-30 GHz)	V Band (40-75 GHz) W Band (75-110 GHz)				
Extremely High Frequency (EHF)	K Band (30-40 GHz)		30-300 GHz	Inter-satellite links, military survivable satcom	Microwave data links, active denial system
	L Band (40-60 GHz)				
	M Band (60-100GHz)				

* Provided by Secure World Foundation

** North Atlantic Treaty Organization

*** Institute of Electrical and Electronics Engineers

Figure 6: Radiofrequency Bands

[Source: SSI Issue Guide: Condition and Knowledge of the Space Environment
Managing Space-Based Resources, August 2020, source:
<https://spacesecurityindex.org/2020/08/managing-space-based-resources/>]

3.7. Target surveillance

As has been strongly mentioned in the previous sub-sections, reconnaissance & spy satellites provide a trove of information and data from a faraway location and relay the data back to military personnel on the ground, regarding persons, governments, military forces, etc. They can provide real or almost real-time information about people and vehicles movements, vessels and even small dimension³⁰ objects.

Satellites can be used for both strategic and tactical purposes. Strategically, satellites are used to monitor enemy forces, their movements and activities, and their resources. This information can be used to plan strategies and determine the best way to respond to threats. At the tactical level, satellites provide real-time information about troop locations and movements, allowing commanders to adjust plans accordingly. Satellites also provide valuable information about weather conditions and topography. This can be used to assess the potential impact of a mission or determine the best route to avoid adverse conditions.

³⁰ "Satellites equipped with higher-resolution imaging systems, such as those used for military or intelligence purposes, can capture objects as small as a few centimeters in size" – available: <https://ts2.shop/en/posts/can-a-satellite-see-a-car>

Target surveillance satellites, a prominent subset of reconnaissance satellites, are instrumental in shaping global intelligence and defence strategies. Serving primarily to monitor specific terrestrial or space objects, their significance extends far beyond mere observation, impacting areas such as military decision-making, treaty verification, and geopolitical maneuverings [57].

Their mission are very useful specifically at the sector of early warning, such as of potential threats, or of monitoring adversaries' troops etc. All this valuable information can be assessed and evaluated regarding detections of upcoming invasion and alert countries under threat. In addition, in such scenario, there is time to alert countries under threat and provide the necessary time for taking measures for the protection of the population, whereas there could be information about the size and strength of a country's military force.

In general, surveillance satellites play a remarkable role in protecting national security around the world. By monitoring the activities of enemy nations, satellites can provide early warning of potential threats and the interested party can use the intelligence in order to develop strategies to counter possible attacks [58].

Last but not least, satellite surveillance can also be used to monitor terrorist activities such as suspicious transportation, illegal arms trafficking, and movement of people. By closely monitoring these activities, the military can take action to prevent or deter potential threats. Overall, satellites do and will greatly improve the ability of military and defence personnel to monitor and respond to various threats, making it easier at the same time to take more informed decisions about how best to protect employee safety and national security.

3.8. Current capabilities, gaps, and future needs of European space-based systems to support security policies

Satellite Communication Services

The SPASEC³¹ report outlines several satellite communication systems, detailing their military and civil applications. The UK's SKYNET IV and V systems, which encompass UHF, SHF, and X-Band capabilities, represent advanced military communication infrastructure, with SKYNET V being a privately financed initiative. Italy's SICRAL system supports military operations with its S-Band, UHF, SHF, X-Band, and EHF capabilities. France's SYRACUSE II and III systems, equipped with SHF and EHF, and Spain's SPAINSAT and XTAR-EUR, which offer SHF and X-Band services, are vital components of Europe's military communications network. Germany's SATCOMBw Stufe 2, scheduled for launch in 2008, will include UHF, SHF, X-Band, and other frequency bands. NATO's communication satellites, such as NATO IV and NATO SATCOM Post 2000, use UHF, SHF, and X-Band frequencies for military operations. Additionally, commercial systems from EUTELSAT and INMARSAT provide a variety of communication services in bands like Ku, C, and L-Bands.

³¹ Report of the Panel of Experts on Space and Security, <https://op.europa.eu/en/publication-detail/-/publication/7daacd2c-56f5-444b-b2e8-7e9af11b050f/language-en>

Earth Observation Services

Europe has a robust capability in Earth observation, primarily in the civil sector, with a growing shift towards military applications. Notable systems include HELIOS I and II optical satellites, operated by France, Italy, and Spain, offering high-resolution imagery, and France's PLEIADES system, providing very high-resolution optical imaging. Germany's SAR LUPE and Italy's COSMO-SkyMed deliver Synthetic Aperture Radar (SAR) capabilities essential for high-resolution radar imagery. ESA's ENVISAT and ERS-2 satellites, equipped with multiple sensors, support environmental monitoring and various observation purposes. Germany's RapidEye constellation provides high-resolution optical imaging.

Position Navigation and Timing Services

The GALILEO system is a significant advancement for Europe in civil navigation, offering precise and secure services crucial for applications like emergency response and civil protection. This system complements the existing GPS (USA) and GLONASS (Russia) systems, with GALILEO expected to be fully operational post-2008.

Space Surveillance Systems

Ensuring the protection of space assets is a fundamental requirement, necessitating an independent European space surveillance system. Such a system would monitor satellites and debris, safeguarding the operational integrity and safety of space-based services.

Harmonisation of Standards and Interoperability

Interoperability is crucial for the effective use of satellite services across different user communities. The report emphasizes the need for standardized interfaces and procedures to seamlessly integrate satellite services into existing operational frameworks, thus enhancing overall efficiency.

Cross-Cutting Issues

The report addresses several cross-cutting issues, including the development of a coherent security and defence doctrine based on collective action and joint operations. It highlights regulatory and legal issues such as spectrum management, data policy, and export controls, which are essential for coordinated and compliant use of space technologies. The importance of research and development in forming a coherent security equipment policy is also discussed.

Capability Gaps

The report identifies significant gaps, such as the lack of a coordinated needs assessment mechanism across multiple agencies and interoperability issues resulting from diverse organizational structures. It recommends developing a common security architecture to unify civil and military space efforts and enhance strategic surveillance capabilities.

Recommendations and Future Directions

To address these gaps and future needs, the report suggests developing a common security architecture to unify civil and military space efforts and enhance earth observation capabilities to support security policies. It calls for targeted satellite systems and services

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to address operational needs, emphasizing the importance of a coordinated effort to develop a coherent and integrated approach to utilizing space-based capabilities for security and defence in Europe.

In conclusion, the SPASEC report provides an extensive overview of the current state of European space capabilities, identifies critical gaps, and outlines strategic recommendations to enhance the integration and effectiveness of space-based services in supporting security policies. This strategic roadmap is essential for Europe to maintain and advance its position in global space and security arenas.

Name	Owner	Characteristics	Remarks
SKYNET IV	UK	5 Satellites UHF SHF X-Band	Military/Operational
SKYNET V	Paradigm Se	2 Satellites UHF SHF X-Band EHF	Military/Private Financed Initiative
SICRAL	Italy	1 Satellite S-Band UHF SHF X-Band EHF	Military/Operational
SYRACUSE III	France	1 Satellite SHF X-Band SHF EHF	Military
SYRACUSE II	France	1 Satellite SHF X-Band	Military/Operational
SPAINSAT	Spain	1 Satellite SHF X-Band Ka Band	Military
XTAR-EUR	US/Spain	1 Satellite SHF X-Band	Military
SATCOMBw Stufe 2	Germany	2 Satellites UHF SHF X-Band C-Band Ku-or Ka-Band	Military
NATO IV	NATO	2 Satellites UHF SHF X-Band	Military/Operational
NATO SATCOM Post 2000	NATO	UHF SHF X-Band EHF	Military
HELLAS SAT	Greece	Ku-Band	Commercial/Operational
ARTEMIS	ESA	1 Satellite S-and Ka-Band optical data relay navigation	Operational
SeSat	EUTELSAT	2 Satellites Ku-Band	Commercial/Operational
e-bird	EUTELSAT	1 Satellite Ku-Band	Commercial/Operational
W-Series	EUTELSAT	6 Satellites Ku-Band	Commercial/Operational
HOTBIRD	EUTELSAT	6 Satellites Ku- and some Ka-Band	Commercial/Operational
EUROBIRD	EUTELSAT	2 Satellites Ku-Band	Commercial/Operational
ATLANTICBIRD	EUTELSAT	3 Satellites Ku- and some C-Band	Commercial/Operational
ASTRA	SES GLOBAL	36 Satellites mix of C- Ku and C/Ku-Band Satellites	Commercial/Operational
I-2 I-3 I-4	INMARSAT	10 Satellites C- and L-Band	Commercial/Operational

Figure 7: Satellite Communication Services

[Source: Report of the panel of experts on space and security:

<https://op.europa.eu/en/publication-detail/-/publication/7daacd2c-56f5-444b-b2e8-7e9af11b050f/language-en>]

3.9. Examples from Case Studies

3.9.1 The Persian's Gulf war example

The war in the Persian Gulf, just thirty years ago, marked a new era in the field of military conflicts. The use of new technologies, and more specifically satellite data, was set to profoundly infiltrate modern battle planning and drastically change the previously known factors related to preparing the sides of an armed conflict, so much so that it was dubbed "the first space war. [31]

The chronicle of this unprecedented crisis is set in August 1990 when Iraqi forces under Saddam Hussein invaded Kuwait and occupied it. The novelty of the whole situation lies in the fact that, while Iraq had been threatening Kuwait for several months and the region was monitored by over 60 military and 20 commercial satellites, the Americans managed to accurately predict the Iraqi invasion just a few twenty-four hours before it took place. And this because the information the Americans had and could use did not come from human sources but was based solely on images they had from their reconnaissance satellites. As a result, analysts were divided over whether the deployment of Iraqi troops on the Kuwaiti border was merely a result of a policy of exerting pressure or rather indicated preparatory actions for the declaration of a war.

Only when the reconnaissance satellites³² sent images depicting the movement of resupply and support units to the border, and signal interception satellites detected a significant increase in the volume of telecommunications that far exceeded the usual, did the American intelligence services confidently believe they were on the brink of a military conflict³³. The notorious Gulf War lasted about five weeks with aerial attacks during which critical Iraqi targets were hit with advanced missile systems.

In any case, the assistance provided by the satellite images was undeniable, as it enabled the identification and precise location of the main enemy installations, decrypted their battle formations, and recorded the movement of their troops. In addition to these, other uses of satellites contributed to the communication of the US Department of Defence with the theater of operations, the selection of the final attack area, the improvement of the accuracy of aerial strikes, and the correction of the trajectory of missiles during their flight towards their target [59]. With the capabilities offered by space technology, almost all early warning systems and radars were neutralized, a large number of command and control centers were damaged³⁴, and the use of Iraqi reconnaissance aircraft was deterred.

³² There were at least five (5) military reconnaissance satellites, among which two or three (2 or 3) satellites (KeyHole) KH-11, as well as two (2) Advanced KH-11, but also commercial reconnaissance satellites, such as the American Landsat or the French SPOT. For more information regarding the characteristics of these types of satellites, see Alexandros Kolovos, "PERSIAN GULF: Critical Evaluation of Satellite Systems," National Center for Space Research, Air Force Operational Information Center, Periodic Study #3, (2/1992), pp. 7-10 and 26-27 with the references therein.

³³ see Alexandros Kolovos, "Decisions from Space: Information and Satellite Technology," I. Sideris Publications, Athens 2019, pp. 168-169, where the movements of the Iraqis are detailed a few days before the invasion, such as the relocation of the units of Iraq's Presidential Guard to Basra or the activation of a radar in Southern Iraq that had been used during the war with Iran.

³⁴ The contribution of satellite data in assessing the damage sustained by the enemy was equally crucial, in terms of reorganizing forces and launching new attacks on targets that had remained untouched until then.
G. - E. Giataganas

For this reason, it is no coincidence that the Gulf War marked the first-time use of Earth observation satellites in monitoring the theater of operations, changing their usual use, which until then consisted of verifying disarmament agreements.

3.9.2 The Yugoslavia case

Another modern example of the advantages of satellites in military operations is the case of Yugoslavia. Approximately fifty (50) satellites of American, British, French, and NATO origin supported NATO's military campaign against the Federal Republic of Yugoslavia. As a result, it's not an exaggeration to say this was the largest historical concentration of space resources in a single war [60]. If, in 1991, the "Desert Storm" operation in the Persian Gulf demonstrated that space technology was to become the primary factor for success in an armed conflict [61], the operation in Yugoslavia in 1999 proved that the power of information on the battlefield had surpassed conventional methods and means.

The contribution of satellites includes extracting information from reconnaissance satellite images, intercepting signals, charting weather and climatic conditions, monitoring telecommunications, and identifying fixed and mobile targets on the ground. Specifically, earth observation satellites³⁵ were programmed to pass over the contentious Balkan area twice a day, providing battlefield commanders with necessary information on both the targets to be attacked and the extent of the damage inflicted. The images transmitted provided reliable information, even when flying over points of interest at night or in adverse weather conditions. Regarding fixed targets like tanks or missiles, satellites could locate them even if they were hidden in dense forests.

3.9.3 The armed conflict in Afghanistan

In 2001, the eyes of global public opinion were turned to New York and the terrorist attack of September 11th, which resulted in the collapse of the Twin Towers at the World Trade Center with the well-known tragic toll of thousands dead and injured. Gradually, however, attention shifted to Afghanistan, a region in south-central Asia, which is under the administration of factions, among which is the self-proclaimed Taliban government that controls the capital, Kabul, and two-thirds (2/3) of the country.

On October 5th, less than a month after the terrorist attack in New York and just five days before the start of the attacks that would be codenamed Operation Enduring Freedom, the U.S. launched an Advanced Keyhole satellite over Afghanistan to assist in their operational plans and stay informed about the movements of various groups inland. In fact, just two days later, on October 7th, in order to prevent public opinion and the media from having a picture of the area that was to become a battlefield, the American government decided to pay for the exclusive rights to commercial satellite images of Afghanistan³⁶, even though the corresponding images from its military satellites were obviously much better³⁷.

³⁵ It was about the reconnaissance satellites of the Lacrosse and KH-11 type.

³⁶ to ensure these exclusive rights, the American government had to enter into a multimillion-dollar agreement to prevent the images of Afghanistan from being channeled to private individuals, business entities, and state partners. These images came from the commercial satellite Ikonos-2 and under normal circumstances could be used for purposes such as mapping, spatial planning and zoning, environmental and agricultural analysis, oil exploration, risk management, natural disaster assessment, etc.

³⁷ The Satellite Wars, accessed: 20/04/2023, available: <http://www.spacetoday.org/Satellites/YugoWarSats.html>

With this move, the Americans were not just trying to obstruct public opinion and the news media from getting a picture of their area of interest. They wanted the same results for the Taliban³⁸. Their exclusion from commercial satellite photos might seem insignificant, but the reality is quite different. With a resolution of one meter³⁹, they could provide a picture of the number, type, and color of vehicles or vessels in an area, the presence or absence of vegetation, and the size and features of buildings.

However, beyond the U.S. satellites, the region was also observed by satellites of their international supporting powers, aiming to assist in the fight against terrorism. Special mention should be made of the Russian satellites, one Earth observation satellite and one telecommunications satellite, whose contribution was crucial on the operational field. Regardless, the combined use of all space technologies that the Americans collectively had at their disposal became a powerful tool in confronting the enemy, giving them a position of power and superiority.

3.9.4 The second war in Iraq

After the end of the war in the Persian Gulf, nothing was the same. Americans would forever be suspicious of Iraqis and their grand plans, which international propaganda portrayed as reaching the creation of weapons of mass destruction. The placement of United Nations inspectors in Iraq, tasked with ensuring that Iraq destroyed all stockpiles of chemical and biological weapons and long-range ballistic missiles, always acted as a detrimental factor in the relations between the two countries.

Ultimately, the act that signaled a new period of crisis in the region was the removal of the inspectors in 1998 on Saddam Hussein's orders and the simultaneous response of the US government to consider this move as a legitimate reason for military action [31]. Naturally, the uncooperative stance of the Iraqis fueled the belief of Americans and British that Iraq still had stockpiles of chemical and biological weapons, and if not already, would surely acquire a nuclear arsenal in the near future. This polarized atmosphere, combined with the terrorist attack of September 11th, 2001 that was linked to Al Qaeda and thus indirectly to Saddam Hussein who maintained close relations with the organization, was more than enough to signal the start of a second war against Iraq.

In late November 2002, Saddam Hussein invited the UN inspectors back to continue their work. Meanwhile, satellite images⁴⁰ from the area showed suspicious activity. Soon after, in a related UN Security Council session, the Americans decided to share photographs⁴¹, audio recordings from intercepted communications, and reports from human sources to prove their claims that Iraq continued to develop weapons of mass destruction [31]. They obviously sought the support of other Security Council member states for their decision to

³⁸ For example, a satellite image of the Kandahar airport might reveal the operational tactics of the Americans if it fell into the hands of the Afghans.

³⁹ It is speculated that the resolution capability of military satellites could reach ten centimeters, a claim that is not confirmed, yet it is a strong belief among intelligence analysts.

⁴⁰ For technical details regarding the satellites that were flying over Iraq during that period, see ref. 'The Satellite Wars' on the website: <http://www.spacetoday.org/Satellites/YugoWarSats.html>

⁴¹ It is perhaps the largest historical disclosure of classified material in order to support American diplomacy in its declaration of war against Iraq.

attack Iraq, even though they had already moved American troops to the wider region of the Iraqi state.

The support never came, unlike the invasion by US forces that took place on March 20, 2003, and lasted several weeks. The stake this time was prevention against oppression. There was no tangible, visible danger like in Korea, Vietnam, or the Persian Gulf [62], but there was a suspicion of danger fueled by inanimate intelligence sources, especially satellite images with sometimes perhaps arbitrarily interpretive conclusions. Soon, because of this, came the questioning and then the critical stance against the war in Iraq, both from public opinion and from political entities, once supporters of the US government's choice.

4. Use of satellites for Security purposes

Of course, satellites are not used solely for defense and military purposes. This is just one aspect of their application, often unnoticed by most people. On the contrary, the use of satellites for security purposes has a more noticeable impact on everyday life. Below are some of the most important categories in this regard.

4.1. Borders surveillance

Border. Society of Satellite Professionals Internationals (SSPI) pose the following definition: «It can literally be a line in the sand or a fence made of concertina wire. A guard outpost on a busy road. A strip of unoccupied beach. A patch of trackless forest. A river snaking its way between two nations. Invisible, yet vital, borders define where one place ends and another begins. Borders are in the mind and heart as well as the laws of a nation, and they represent a barrier or a beginning, safety or threat, opportunity realized or opportunity denied».⁴²

Every country or union of member states do in a daily basis what is necessary to maintain their national sovereignty of sea, air and land, providing in the same time a sense of security to its citizens and countering threats and incidents that attempt to undermine their governments and polities. Border surveillance is one of the most neuralgic points of the modern society, as it is really difficult to monitor, check and prevent any unauthorized entry to a country from all the possible ways. Once again, the satellites have a special position in providing strategic and operational support to this issue.

It is widely known from United Nations (UN) reports that millions of people worldwide have been compelled so far⁴³ to be displaced from their homes due to armed conflicts all over the Earth, with a quite large percentage of these people, trying to reach to other peaceful countries, seeking the safety and a new start. In addition, at the borders of countries for decades, illegal acts have been carried out, such as the trade of drugs, weapons, etc. Nowadays, in many countries, it is observed violation of their borders, of course for many different reasons, so these countries feel obliged to defend their borders against trespassing, even if they contend with the moral and practical challenges posed by waves of refugees, smugglers, and traffickers [63].

Towards this direction, satellites are used more intensely in order to secure the borders and ensure in the most possible way the national security. Satellites are capable of monitoring in real-time large areas of land and sea, detecting suspicious - illegal activities and movements, such as border crossing of people, vehicles, ships, aircrafts, vessels etc that otherwise would not be perceptible.

In addition, satellite-based monitoring systems provide intelligence and data to the border security forces, as the technology used can detect unauthorized crossings while at the same time it is cost-effective, as it is not required deployment of personnel to the borders [64].

⁴² How Satellites Secure the Border, By Better Satellite World – SSPI, accessed: 20/06/2023, available: <https://interactive.satellitetoday.com/how-satellites-secure-the-border/>

⁴³ According to a 2016 UN report, that number rises to almost 65 million displaced people

For instance, in European Union, among other sectors, the EU Earth Observation Program Copernicus has been deployed for the border and maritime surveillance.

Copernicus, as referred in the official European Union's (EU) website homepage, is «Europe's Eyes on Earth | Looking at our planet and its environment for the benefit of Europe's citizens»⁴⁴. Copernicus has a wide range of services⁴⁵ to the following sectors: Atmosphere, Marine, Land, Climate Change, Security and Emergency.

Specifically, the Border Surveillance component is managed by Frontex, the European Border and Coast Guard Agency, which helps EU member states detect irregular migration, fight cross-border crime and combat terrorism. This component provides near real-time data on the EU's external land and maritime borders, supporting the EU External Border Surveillance information exchange framework⁴⁶.

Copernicus data allow Frontex to achieve its primary objective – to increase situational awareness at European external borders by mapping, monitoring and providing risk assessments.

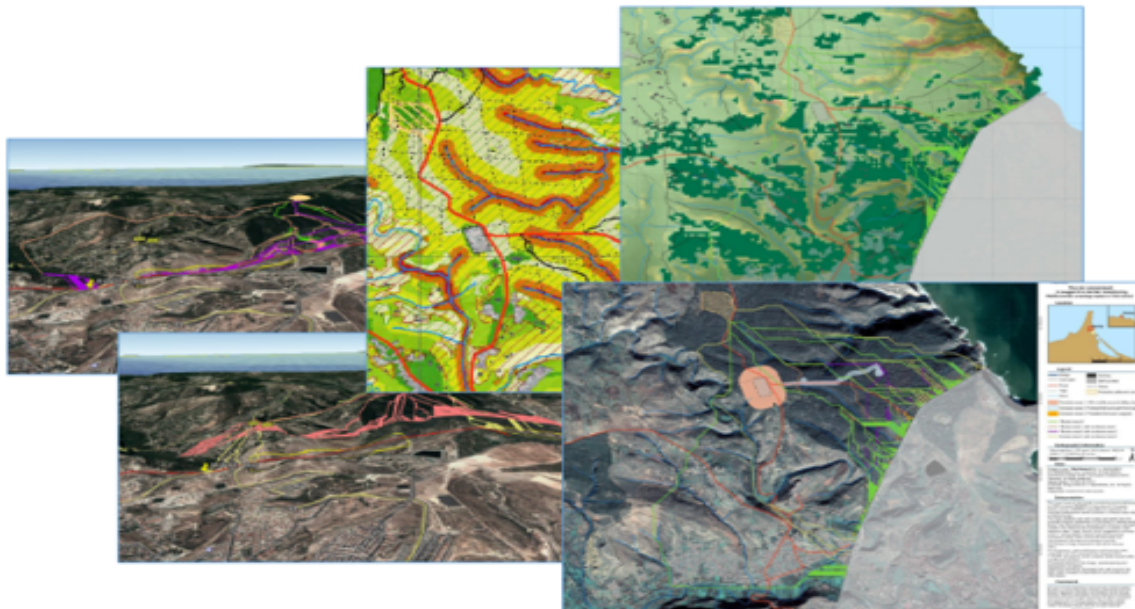


Image 14: Land surveillance analytical product (Credits: Frontex)

[Source: https://insitu.copernicus.eu/FactSheets/CSS_Border_Surveillance]

⁴⁴ more information available: <https://www.copernicus.eu/en>

⁴⁵ more information available: <https://www.copernicus.eu/en/copernicus-services>

⁴⁶ more information available: https://insitu.copernicus.eu/FactSheets/CSS_Border_Surveillance

4.2. Environment monitoring

Satellites play a major role in environmental monitoring, providing valuable data for studies and understanding various aspects of the Earth's environment. Through all this many year information flow transmitted by the respective satellites, scientists can make assessments about the climate change, upcoming or past natural disasters and in general the changes that take place in this vast ecosystem. More specifically, environmental satellites provide valuable information about the following fields⁴⁷ :

- **Climate Monitoring:** satellites equipped with sensors can measure various climate-related parameters such as temperature, humidity, and greenhouse gas concentrations such as carbon monoxide, carbon dioxide and methane. They also can track the impacts of climate change, such as global temperatures, weather patterns and so on⁴⁸. These satellites help scientists track long-term climate trends and understand the impacts of human activities on the environment [65].
- **Weather Forecasting:** weather satellites provide real-time data on atmospheric conditions, cloud cover, and precipitation. This information is crucial for accurate weather forecasting, which is essential for disaster preparedness and agriculture planning [66].
- **Natural Disaster Management:** satellites are instrumental in monitoring and managing natural disasters such as hurricanes, wildfires, floods, and earthquakes. They can provide early warning systems and help authorities coordinate emergency responses [67].
- **Deforestation and Land Use:** deforestation is a significant source of greenhouse gases and reduces biodiversity⁴⁹. Satellites equipped with high-resolution imaging sensors enable monitoring of deforestation, changes in land cover, and urbanization. This information is vital for sustainable land management and biodiversity conservation [68].
- **Ocean Monitoring:** satellites can observe ocean currents, sea surface temperature, and changes in sea levels. This data is crucial for understanding ocean circulation patterns, studying marine ecosystems, and monitoring the impact of climate change on oceans [69].
- **Air Quality Monitoring:** satellites equipped with sensors can measure air pollutants and provide data on air quality. This information is valuable for assessing the impact of industrial activities and urbanization on the environment and public health [70].

⁴⁷ more relevant information for all the fields available to website <https://ts2.space>

⁴⁸ more relevant information available to <https://ourworld.unu.edu/en/how-things-work-environmental-satellites>

⁴⁹ ibid

4.3. Humanitarian aid

Undisputedly, the assurance of human safety and security is above all other aspects. It could not be overlooked in the case of satellites uses for civilian purposes. In fact, there are many cases of sudden emerge if humanitarian aid caused by natural disasters or other big scale events resulting to fatalities, injuries and other sever impacts, such as tsunami strikes, big earthquakes etc., where humanitarian aid is extremely important and urgent to be delivered to the affected people.

Satellites play a key role in supporting the emergency first responders to their strategical and operational preparation of disaster relief plans. The constant evolution of technology makes the uses of satellites for governments more necessary than ever, towards the effectiveness during a disaster relief but also proactively. For instance, in a case of wide range natural disaster it is a possible scenario that most of the communications are failed or are so loaded that cannot be available for all the interested parties and affected people. Thus, satellites are able to provide communications and internet to facilitate the mission of the first responders (emergency medical services, police and fire departments) on the field but also critical infrastructures of the affected area such as airports, hospitals and other crucial infrastructures for the disaster management and recovery. For this reason, communication satellites are ideal for providing backhaul to mobile phone devices when the terrestrial infrastructure is out of services, especially in remote and steep areas, where there is imminent danger for human lives [71].

An example of such a biblical catastrophe took place in Sulawesi, an Indonesian island in 2018. All started by a very powerful earthquake measured at 7.5 degrees of Richter scale. As a result, the soil under many houses liquidated, in addition a 15 – meter tsunami created and hit the island and last but not least the volcano Soputan. The first responders through satellite images provided by Maxar, a private space technology company, managed to locate where families were potentially trapped or waiting for relief, determined which transportation routes were still open while made direct efforts to clear the blocked ones and identified safe sources of drinking water [72].

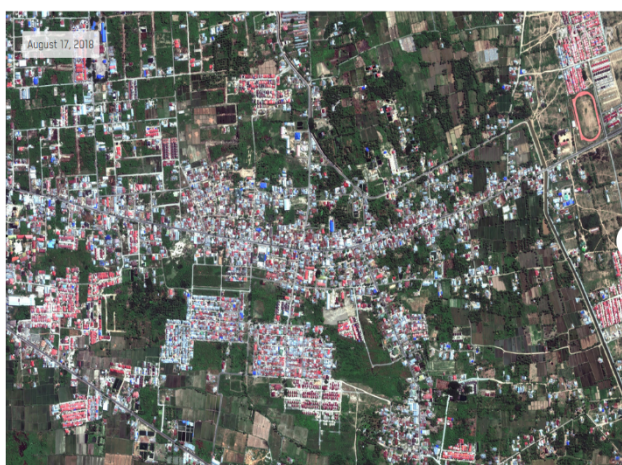


Image 15: Before satellite image of Palu City in Indonesia



Image 16: After satellite image of Palu City in Indonesia

[Source: Satellite Imagery helps Indonesian Earthquake victims, <https://blog.maxar.com/for-a-better-world/2018/satellite-imagery-helps-indonesian-earthquake-victims>]

4.4. Search and rescue

Satellites play also a key role in search and rescue operations, like a shipwreck or a person's injury, as with their support the rescue teams are facilitated to locate people in distress more quickly and accurately than ever. As was described previously, satellite imagery is extremely useful to draft a route, avoid obstacles, in general make the best option in an area of interest from aspect of security and time saving. However, for search and rescue navigation satellites are employed for the geolocation accuracy.

The Cospas-Sarsat System⁵⁰ is comprised of satellites constellations that carry SAR (Search and Rescue) instruments on board. These satellites are set up to detect 406 MHz distress beacon signals⁵¹ that have been activated from a device on Earth. Obviously, with the “eyes” or “ears” in this case from the Space it is easier to detect these signals and respond in short time. The coverage area depends of course on the type of satellite, while there are 45 countries and organizations that participate in Cospas-Sarsat system⁵².

There are three types of satellites that are part of the above system, according to their orbit, and these are: LEOSAR, MEOSAR and GEOSAR [73].

LEOSAR was the first category of satellites used for search and rescue back in the early 1980s. Their low altitude permits only a small area of coverage (6% of Earth) and due to the small number of the constellation LEOSAR must pass over a distress signal and be in view of LEOLUT (Local User Terminal – Cospas-sarsat ground station) to transmit the signal, so there is a non-continuous coverage.

GEOSAR are orbiting over a fixed spot on the surface and this permits a wide area of coverage (42% of Earth) and subsequently they are able to detect and identify a 406 MHz distress beacon that has been activated. This is real time saving as SAR first responders as they can begin the initial verification of the alert by using the relevant Registration Database for beacons. Even more important, if a GPS chip is integrated into the beacon, in a matter of a few minutes the exact geolocation of the beacon is identified.

MEOSAR are the latest addition to the Cospas-Sarsat system and essentially are GNSS (GPS, GLONASS and GALILEO) satellites with also a wide area of coverage (33% of Earth) providing PNT to GNSS receivers which use the received data to determine the location. MEOSAR provides near instantaneous global detection of emergency beacons, improved location accuracy and high levels of redundancy and availability.

Year	People Rescued	SAR Events →	Aviation	Land	Maritime
2022	3,223	1,144	20%	39%	41%
2021	3,623	1,149	18%	45%	37%
2020	2,278	951	23%	37%	40%

Figure 8: Statistics about assist of Cospas - Sarsat from 2020 to 2022
[Source: Cospas-Sarsat website, Cospas – Sarsat System Data No.48, Dec. 2022]

⁵⁰ more information available at Cospas-Sarsat website: <https://www.cospas-sarsat.int/en/>

⁵¹ the beacon is a radio transmitter that can be activated in a life-threatening emergency to summon assistance from government authorities

⁵² <https://www.cospas-sarsat.int/en/about-us/participants>

4.5. Civil security and protection

Satellites significantly enhance civil security and protection by enabling advanced technology applications in various daily activities and operational sectors, such as telecommunications, Earth observation, and navigation. These technologies are extremely beneficial in crisis management, providing real-time data for improved situational awareness, which is critical for responding to natural disasters, cyber threats, and geopolitical issues.

In line with these advancements, the European Space Agency (ESA) introduced the Civil Security from Space (CSS) Program⁵³, a strategic initiative designed to handle civil security and crisis situations using advanced space technologies. This initiative addresses significant issues like natural disasters, cybercrime, and geopolitical instability, aiming to safeguard European citizens and critical infrastructure. The systems used are crucial for disaster response, humanitarian aid, law enforcement agencies (LEA), and the protection of critical infrastructure. The CSS Program ensures secure and interoperable communication networks, enabling efficient coordination during emergencies.

The CSS program aims to deliver end-to-end solutions encompassing data collection through sensors, secure communication infrastructures, and sophisticated data processing capabilities. These systems are designed to provide real-time, actionable insights to civil security and crisis management leaders, enhancing their ability to respond quickly and effectively. The program employs cutting-edge technologies, including advanced Earth observation, artificial intelligence, high-performance computing, and quantum technologies. This integration seeks to provide a comprehensive understanding of crisis situations, facilitating better decision-making and management.

Collaborative efforts are a cornerstone of the CSS program, with the ESA promoting partnerships with industries, government entities, and institutional stakeholders. The program supports collaboration through co-funded projects, user consultation groups, and industry associations to develop interoperable and scalable solutions. Emphasizing the need for responsive, secure, and resilient systems, the CSS program is designed to be adaptable and future-proof, accommodating new technologies and continuous service improvements.

More specifically and regarding disaster management and emergency response, satellites provide real-time data and imagery essential for monitoring natural disasters like hurricanes, earthquakes, and floods. This data helps assess the extent of damage, coordinate emergency response efforts, and provide timely assistance to affected areas. For example, the ESA utilizes its satellite capabilities to support disaster management through the Copernicus Emergency Management Service⁵⁴, which provides accurate and timely information for emergency response operations.

Satellite data also supports urban planning and public safety by providing detailed maps and geospatial information. This helps efficiently allocate resources, plan infrastructure, and ensure the safety of urban populations⁵⁵. For instance, satellites can monitor traffic

⁵³ Civil Security from Space, <https://connectivity.esa.int/civil-security-space>

⁵⁴ Information for emergency response and disaster risk management, <https://emergency.copernicus.eu/>

⁵⁵ Xueman Yang, How geospatial technology can help cities plan for a sustainable future, <https://blogs.worldbank.org/en/sustainablecities/how-geospatial-technology-can-help-cities-plan-sustainable-future>

patterns, detect structural weaknesses in buildings, and assist in planning evacuation routes during emergencies⁵⁶. Although not purely civil, the dual-use nature of many satellite systems means they also play a role in national security by providing surveillance and reconnaissance capabilities. This helps maintain situational awareness and protect critical infrastructure from potential threats⁵⁷.

From a LEA perspective, satellites are vital for intelligence gathering, providing essential data for identifying and mitigating threats. Their capabilities include high-resolution surveillance and observation, enabling the monitoring of large areas and the detection of suspicious activities. Continuous observation is crucial for tracking criminal or terrorist activities and uncovering hidden operations, such as weapons storage or illicit drug manufacturing. Advanced imaging technologies, like synthetic aperture radar (SAR) and thermal imaging, further enhance the detection of concealed activities, even through dense foliage or at night. Routine satellite monitoring helps identify patterns that indicate illegal activities, such as changes in traffic around hotspots or unexpected construction, alerting authorities to potential threats. In crime prevention, satellites provide proactive surveillance and enable timely interventions.

They monitor national borders to detect and prevent illegal crossings, human trafficking, and smuggling, allowing border patrol agents to respond quickly. In maritime areas, satellites track vessel movements to detect illegal fishing, smuggling, and piracy, providing continuous data on ship locations and behaviors. Urban surveillance is improved, especially in high-crime neighborhoods and during large public events, facilitating quick responses to potential threats and better crowd management.

Satellites play a crucial role in criminal investigations by providing detailed and accurate data that can be used as evidence or to guide investigative efforts. Satellite imagery aids in forensic analysis, helping reconstruct events and analyze suspect movements. Historical satellite data offers perspectives for analyzing long-term trends and investigating past events. Combining satellite data with other geospatial information enables comprehensive crime scene analysis and precise tactical planning.

Furthermore, satellites boost international law enforcement cooperation by facilitating secure and timely intelligence sharing between countries, aiding in tracking international criminal networks and terrorist activities. They ensure effective coordination in multinational operations and support training programs through real-time data and communication links, enhancing collaboration and interoperability among law enforcement agencies. In summary, satellites greatly enhance law enforcement and intelligence operations through comprehensive surveillance, real-time data, and robust communication capabilities. They aid in crime prevention, improve investigative processes, and foster international cooperation, making them essential for maintaining internal security and public safety.

⁵⁶ Smart Urban Planning With Remote Sensing Techniques, <https://eos.com/blog/smart-urban-planning-with-remote-sensing-techniques/>

⁵⁷ Nicholas Eftimiades, Small satellites: The implications for national security, <https://www.atlanticcouncil.org/in-depth-research-reports/report/small-satellites-the-implications-for-national-security/>

PART C. SECURITY IN SPACE

So far in this dissertation took place an analysis about the Security from Space. However, the most challenging part is met in the Near Space and thus, Security in Space is a more explicit and inseparable part of this marvelous and charming area of interest.

The Cold War is a widely known area that had started a few years after the winning US-USSR-UK coalition of the World War II. Historians do not fully agree on the demarcation of the beginning of the period, but the period from 1945 to 1991 is generally as the accepted one. Most experts sign this start on 12th March 1947 when the Truman Doctrine took place and its end on 26th December 1991 with the dissolution of the Soviet Union.

The space race was an intense element between Cold War's rivals, the United States and the Soviet Union to achieve superior spaceflight capabilities. It had its origins in the ballistic missile-based nuclear arms race between the two countries after World War II and reached its peak with the more specific race to land on the Moon in the midst of the US Moonshot program and the Soviet Union. The technological advantage demonstrated by spaceflight was considered necessary for national security and became part of the symbolism and ideology of the time. The space race brought pioneering launches of artificial satellites, robotic space probes to the Moon, Venus, and Mars, as well as manned spaceflight into low orbit by Earth and eventually to the Moon⁵⁸.

In addition, this scientific and technological expanse contributed to the enhancement of the leading nations' defence even in the Space and the first space weapons appeared during the Cold War era, and more specifically after the Soviets had launched the first human made artificial satellite Sputnik 1, when the USA responded with the first ASAT weapon called Bold Orion⁵⁹ Weapon System 199B, after that USSR responded with the Polyot interceptor⁶⁰.

Of course, since the far 1960's there plenty of different types of space weapons and mostly, not only from the USA and Russia, but also other countries such as China, Iran, North Korea, India, France, Israel, Japan and UK. Of course, this status could be really challenging in a case of military conflict among countries who would use space weapons, as this could affect with an extremely severe impact the entire world.

Towards this direction and given the looming potential future threat, especially after the development of ICBMs, the most well-known Outer Space Treaty - a multilateral constitution that forms the basis of international space law - was negotiated and drafted under the auspices of the UN, ratified initially by USA, UK and Soviet Union in 1967. 56 years later more than 100 countries have been parties to this Treaty, which defines the Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies⁶¹. Of course, there are also other negotiated treaties regarding the human activities on Space, as there is a constant need for update and adaptation to the development of technologies, the geostrategic interests as well the new challenges.

⁵⁸ Space Race, accessed: 20/10/2023, available: https://en.wikipedia.org/wiki/Space_Race

⁵⁹ Mark Smith, Anti-satellite weapons: History, types and purpose, last updated 10/08/2022, accessed: 10/10/2023, available: <https://www.space.com/anti-satellite-weapons-asats>

⁶⁰ Anti-satellite weapon, available: https://en.wikipedia.org/wiki/Anti-satellite_weapon

⁶¹ Outer Space Treaty, available: https://en.wikipedia.org/wiki/Outer_Space_Treaty

5. Threats of satellites in Space

Threat to satellites can be divided in unintentional threats (natural hazards) and intentional (human-made) threats in Outer Space.

5.1. Intentional (human-made)

The key to security in space is the security of the satellites themselves. There are human-made threats caused by anthropogenic activities and include disruption of satellite services and even intentional attacks on space assets. The most effective way to protect satellites is to prohibit the testing, development and deployment of antisatellite (ASAT) weapons (Stein, 1988). However, the 1967 Outer Space Treaty does not ban these antisatellite activities.

5.1.1. Space Weapons. Categories

Taking into consideration the almost 9.000⁶² thousands of satellites and the artificial objects that are orbiting the Earth the last 6 decades, at altitude of some hundreds kilometers to some thousands kilometers, it makes sense that the Near Space has a really “heavy traffic”.

What are space weapons and what does space weaponization mean? The answer depends largely on one's perspective, and the rhetoric used by different countries on the subject suggests that they have very different understandings of what constitutes space weapons as well as the types of systems and activities they consider to be legitimate uses of space [74].

According to Union of Concerned Scientists [75], the term space weapon commonly refers to:

(a) Any weapons (whether land-, sea-, or air-based) able to damage a satellite or interfere with its functioning. These weapons are called anti-satellite (or ASAT) weapons. Weapons that interfere with a satellite's ground stations or ground-based communications receivers are typically not considered ASAT weapons.

(b) Any space-based weapons intended to attack targets in space or on the ground. These weapons include space-based ballistic missile defence interceptors and ground-attack weapons.

Therefore according to the above definition, in the first case, space weapon is considered a weapon of any kind that hits or interrupts a target that is located in Space. Thus, the characteristic term ASAT implies that the hit of the target is inextricably linked spatially with the Space, whereas in the case that a weapon is used to destroy or interrupt the ground infrastructure that supports and monitor targeted satellite's functions, is not treated **of**

⁶² Orbiting now, active satellite orbit data, accessed: 23/10/2023, available: <https://orbit.ing-now.com/#main>

course as a space weapon. In the second case, space weapon is considered any space-based weapon that is used to hit target in space or on the ground. Once again, the weapon is inextricably linked spatially with the Space. Subsequently, any weapon used to hit a target in the Space, or any weapon located in Space is used to hit any target, both fall into the category of the Space weapon.

The proposed framework so far from Todd Harrison, director of CSIS's Aerospace Security Project, classifies the space weapons according to the domains in which they originate and have effects (Earth-to-space, space-to-space, and space-to- Earth), as well as the physical means by which these effects are achieves (kinetic and non-kinetic). [88]

Thereafter, there are six (6) main large categories of Space weapons and one (1) category not typically considered space weapon, as follows : Space-to-Space weapons – kinetic and not kinetic, Earth-to-Space weapons – kinetic and not kinetic, Space-to-Earth weapons – kinetic and not kinetic and Counterspace weapons.

For instance, kinetic and non-kinetic space-to-space weapons include on-orbit projectiles or microwaves. Kinetic and non-kinetic Earth-to-space weapons include projectiles or jammers, dazzlers, and cyberattacks. Kinetic and non-kinetic space-to-Earth weapons include jammers, lasers, or projectiles that come down from orbit.

However, no one can discriminate uniquely the space weapons to specific unique categories. In addition, other factors also define the space weapons, such as:

- their "nature" type, e.g. whether they are conventional or nuclear,
- their location, e.g. whether they are stationed on Earth or in orbit,
- their debris contribution, e.g. orbital debris creation,
- their tactical use, e.g. whether they are used for offense or self-defence [76],
- their characteristic type, such as directed energy weapon, or delivering mass with kinetic energy or chemical energy (explosives) [77]
- their origin-to-target type, e.g. Space-to-Space, Space-to-Earth, Earth-to-Space
- their respective subcategories and attributes, such as directed-energy weapons, kinetic-energy weapons against missile targets, kinetic-energy weapons against surface targets, mass-to-target and space-based conventional weapons against surface targets [77]
- their effect on the target, e.g. temporary or permanent, reversible or nonreversible

Below, there is a listing and reporting of the Space Weapons, regarding to their special characteristics.

Kinetic Energy Weapons (KEWs)

Weapons of kinetic energy, refer to arms that are specifically aimed at their target, annihilating it through the mechanical impact of collision. The higher the relative speed between two objects, the greater the potential kinetic energy that can be converted into destructive force upon collision. Given the high velocities at which satellites travel, an impact with even a minor object can result in significant damage. Moreover, a collision that doesn't completely destroy the satellite could still induce a state of uncontrolled rotation or tumbling. In any case, the collision creates large amounts of debris, creating issues for the already existing orbiting satellites and the future ones.

Due to the high velocities at which satellites traverse space (approximately 4-5 kilometers per second in low orbit), any encounter with an object can prove calamitous. This approach

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was employed both by the Chinese in January 2007 and the Americans in February 2008 to incapacitate their respective satellites. Historically, only the former Soviet Union had pioneered the sole operational Anti-Satellite (ASAT) system globally, relying on kinetic energy weaponry. This system comprised a sequence of satellites tasked with the mission of obliterating, impairing, altering orbits, or deactivating adversarial satellites when situated in low orbit. The assaulting satellite, with assistance from its detectors (whether optical-infrared or RADAR), would close in on the target and detonate in close proximity, resulting in the simultaneous destruction of both satellites. This method facilitated the elimination of satellites like those dedicated to reconnaissance and low orbit communication [92].

	Kinetic	Non-Kinetic
Earth-to-Space	Example Direct-ascent ASAT How do they work? A missile fires a warhead or projectile into space to directly strike or detonate near a target satellite. The warhead can be conventional or nuclear. What are the effects? A kinetic Earth-to-space weapon produces space debris that can affect the safe operation of other satellites in affected orbits. Nuclear detonations in space increase the radiation exposure of other satellites and can significantly shorten their lifespan. Have they been demonstrated? Earth-to-space kinetic weapons have been tested by the United States, Russia, China, and India. The United States and Soviet Union tested nuclear weapons in space in the 1960s.	Examples Uplink Jammer, Laser Dazzler/Blinder, Cyberattack How do they work? Non-kinetic counterspace weapons can be stationed on ground, maritime, or airborne platforms and used to affect the operation of satellites or the sensors they carry, without making physical contact. What are the effects? Non-kinetic weapons disrupt or degrade the ability of satellites to function properly. They can have temporary or permanent effects, but they do not generally produce orbital debris or other collateral damage. Have they been demonstrated? Multiple nations have demonstrated these capabilities, including Russia, China, Iran, and others.
Space-to-Space	Examples Co-orbital ASAT, Space-based Missile Defense Interceptors How do they work? A satellite is placed into orbit and maneuvers to intercept its target by striking it directly or detonating a conventional or nuclear warhead in its vicinity. What are their effects? A kinetic space-to-space weapon would produce space debris that can affect the safe operation of other satellites in similar orbits. A nuclear detonation in space would increase the radiation exposure of other satellites and significantly shorten their lifespan. Have they been demonstrated? The Soviet Union tested co-orbital kinetic ASAT weapons repeatedly during the Cold War.	Examples Co-orbital Crosslink Jammer, Co-orbital High-powered Microwave How do they work? A satellite is placed into orbit and uses non-kinetic means (such as a high-powered microwave or jammer) to disrupt the operation of another satellite. What are their effects? They can degrade, disrupt, or destroy a target satellite without making physical contact, producing orbital debris or otherwise affecting other satellites. The effects can be temporary or permanent depending on the form of attack used and the protections on the target satellite. Have they been demonstrated? No open-source examples could be found of such a system being demonstrated, although such tests could look like remote proximity operations to outside observers.
Space-to-Earth	Examples Space-based Global Strike (e.g., "Rods from God") How do they work? Weapons are placed in orbit and, when commanded, deorbit and reenter the atmosphere to strike a target on the Earth. Damage can be inflicted using the kinetic energy of the weapon itself, or a warhead can be deployed from the reentry vehicle (either conventional or nuclear). What are their effects? The effects depend greatly on the type of warhead used (conventional or nuclear) but would be like terrestrial-based ballistic missiles in terms of their ability to hit targets anywhere on Earth with little warning. Have they been demonstrated? While the idea of using space-based weapons for prompt global strike has been contemplated by the U.S. military, there are no open-source examples of such a system being tested.	Examples Space-based Downlink Jammer, Space-based High-powered Laser How do they work? A satellite equipped with a non-kinetic weapon could target forces on Earth, such as a laser used to intercept missiles or aircraft in-flight or a jammer used to interfere with radars or satellite ground stations. What are their effects? When used, the effects would be localized to the target area, but such a system could theoretically strike anywhere without warning. Have they been demonstrated? While the U.S. military has contemplated space-based lasers for boost-phase missile defense, there are no open-source examples of such a system being tested.

Figure 9: Framework for Types of Space Weapons

[Source: Todd Harrison, International Perspectives on Space Weapons, Center for Strategic & International Studies, May 2020]

Directed Energy Weapons (DEWs)

Directed-energy weapons, distinguished by their ability to incapacitate targets through the transmission of energy at the speed of light across extensive distances, stand apart in their own category. In contrast, the other types of weapons incapacitate targets by transporting mass to the designated objective, utilizing either the kinetic energy derived from their own velocity and mass or the stored chemical energy found in traditional explosives for target destruction. Each weapon type functions uniquely, catering to diverse target specifications, exhibiting varied response times, and demanding distinct quantities of weapons in orbital deployment to attain the necessary responsiveness for reaching specific targets promptly when required. [77].

Lasers are commonly identified as directed energy weapons, emitting beams of particles (of course at the speed of light) with the ability to target and disable specific targets, while at the same time have the potential to pose challenges for detectors and solar power sources on satellites in geosynchronous orbit [78]. The laser emits laser at a one specific wavelength, while in the same time all the energy from the laser is focused on a thin beam, thus inducing surface heating and the destruction of the object [79].

Lasers or relatively similar kind of weapon such as microwave weapons (high-powered microwave attacks) can be customized in order the amount of power reaching the target can be adjusted to generate either temporary and reversible impacts or enduring, incapacitating harm. The directed energy weapons however possess drawbacks compared to physical interceptors. They are limited to targeting objects within their line of sight, unless relay mirrors are employed. Additionally, straightforward shields made of reflective, absorptive, or conductive materials can serve as effective defences against them [94].

Two different attacks that could be carried out with the use of laser are dazzling and partial blinding. Dazzling deals with cases where an adversary satellite uses sensors for imaging. During dazzling the sensor is overwhelmed by inundating it with light that surpasses the brightness of the targeted imagery it is attempting to capture. Partial blinding is a more intense attack since at elevated intensities, laser light has the potential to cause permanent harm to the sensors of imaging satellites. The intense light can lead to the ablation or evaporation of detector material, impacting various parts of the detector. This can result in the melting of the material or its delicate electronic connections. Moreover, the substantial temperature gradients generated by the laser beam's heat can induce thermo-mechanical stresses [80].

Space Weapon Comparison

	Directed Energy	Mass-to-Target Weapons		
	Laser, radio frequency, particle beam, etc., weapons	Kinetic energy against missile targets	Kinetic energy against surface targets	Space-based conventional weapons
Targets	Soft, located from the surface to space, ^a any speed	Hardened targets above 60 km moving at great speed	Hardened fixed or slow-moving targets on earth	Hardened targets, either fixed or moving at moderate speeds, surface or air
Effects	Range from nonlethal jamming to lethal heating; finite, inherently "thin" defense	Lethal impact	Vertical, limited-depth penetrator	Inherited from conventional munitions
Responsiveness ^b	Seconds	A few minutes	A few hours	About 10 min plus time it takes weapon to reach target after delivery from space
Number of weapons in constellation	Several dozens	Several dozens for each needed to reach a particular target in desired time	About six in reserve for each needed to reach a particular target in desired time	About six in reserve for each needed to reach a particular target in desired time

^aDepending on wavelength.

^bTime from weapon release to target effect.

Figure 10: Directed Energy and Mass-to-Target Space Weapons comparison

[Source: B. Preston, D. Johnson, S. Edwards, M. Millers, C. Shipbaugh, Space Weapons Earth Wars, RAND, 2002]

Electronic Warfare (EW) in Space

As implied by the title, this type of attack includes weapons whose main mission is to interfere with the Radio Frequency (RF) signals that are transmitted and received by the satellites' antennas by generating noise in the same frequency band and within the field of view of the antenna on the targeted satellite or receiver. The methods used toward this direction is either jamming⁶³ or spoofing⁶⁴.

There are two primary categories of satellite jamming. The first, known as uplink jamming, involves interfering with signals traveling from a ground station or user terminal to the satellite. This is achieved by transmitting a radio frequency (RF) signal at the same frequency as the targeted uplink signal, with the intention of preventing the satellite transponder from distinguishing between the jamming signal and the authentic signal.

The second type, downlink jamming, disrupts transmissions sent from the satellite to ground-based or airborne receivers by using RF signals that replicate the frequency of the downlink signal. The objective is to impede ground users from receiving transmissions from the satellite, and the strength of the jamming signal only needs to match that of the signal being received on the ground. Uplink jamming is considered more challenging due to the need for greater transmitter power to reach a specific satellite's transponders. However, it has the potential for greater impact as it can degrade the satellite's signal for all users. On the other hand, downlink jamming effects are more localized since the jammers must be within the field of view of the receiving terminal's antenna [81].

⁶³ Description provided at <https://www.britannica.com/technology/jamming>

⁶⁴ Description provided at <https://www.forcepoint.com/cyber-edu/spoofing>

Nevertheless, the technology required for disrupting various satellite signals is readily accessible in the commercial market and is relatively cost-effective. Jamming, as a method, is reversible since normal communications can be restored once the jamming device is deactivated. Detection or differentiation of jamming from inadvertent interference⁶⁵ poses challenges, complicating the processes of attribution and awareness [82].

Spoofing constitutes an electronic attack where the attacker tricks a receiver into accepting a fabricated signal, generated by the attacker, as the legitimate signal it intends to receive. Spoofing the downlink from a satellite can be used for transmitting not real or not exploitable data into an adversary's communications systems. Respectively, spoofing the uplink C2 signal to a satellite, could override the authorized access and use it for malicious reasons. Last but not least, through the use of a technique called "meaconing", even encrypted military GPS signals can be deceived. Meaconing doesn't necessitate the decryption of GPS encryption since it involves broadcasting a time-delayed replica of the original signal without decrypting or modifying the data. Like aforementioned in the jammers case, spoofer once manufactured, is relatively inexpensive to produce and deploy in large numbers [82].

Space Weapon Contributions to Military Functions				
For Countering	Directed Energy ^a	Exoatmospheric Kinetic Energy	Endoatmospheric Kinetic Energy	Conventional Ordnance From Space
Air	Destroy ballistic missiles pre-launch and boost phase, aircraft and cruise missiles in flight. Jam air defense sensors and communications	Destroy ballistic missiles post-boost phase	Destroy missiles and aircraft in hardened shelters	Destroy missiles and support vehicles prelaunch
Sea	Destroy aircraft and missile threats to naval forces in flight		Destroy or disable surface ships in port and at sea and supporting shore infrastructure susceptible to vertical penetration	Destroy or disable surface ships in port and at sea and supporting shore infrastructure
Land	Interdict thin-skinned vehicles susceptible to ignition ^b		Destroy fixed targets susceptible to vertical penetration ^c	Interdict mechanized forces in transit and logistics stores and convoys
Information	Jam (or burn out susceptible components) of sensors and communications links		Destroy command bunkers (if not deeply buried)	Destroy communications nodes
Space	Destroy launch vehicles, satellites, and interceptors. Deny navigation signals to satellites. Jam satellite up- down- and/or cross-links. Blind or block satellite sensors	Destroy launch vehicles, satellites, and interceptors attacking satellites	Destroy launch and control facilities	Destroy launch and control facilities

^aFor example, laser, radio frequency.
^bFor example, fuel transport.
^ce.g., munitions storage, POL storage, bunkers, office buildings, etc.

Figure 11: Space Weapon Contributions to Military Functions

[Source: B. Preston, D. Johnson, S. Edwards, M. Millers, C. Shipbaugh, Space Weapons Earth Wars, RAND, 2002]

⁶⁵ U.S. military reported that it was unintentionally jamming its own communications satellites an average of 23 times per month.

Space Mines and Traps

In contrast to a direct ascent ASAT, a co-orbital ASAT enters Earth's orbit. In essence, the deployment of a co-orbital ASAT involves launching a satellite where the weapon itself is the satellite, transforming into a space mine once in orbit. Unlike traditional minefields, space mines are not dispersed in a fixed location.

There are three main reasons for this approach. Firstly, nothing remains stationary in space, necessitating that the mine must orbit itself. A minefield in space would be in constant motion. Secondly, the vast expanse of space, even in close proximity to Earth, makes the likelihood of a space mine randomly causing damage extremely low. Lastly, satellite operators routinely track and maneuver their satellites to avoid collisions with space debris, and encounters with space mines would be similarly avoided. Space mines are inherently guided weapons targeting specific satellites, often achieved through a co-orbital ASAT.

From an energy efficiency standpoint, launching the co-orbital ASAT directly into the same orbit as the target is most effective. However, this restricts the co-orbital system to targeting satellites with an inclination equal to or higher than the latitude of the launch pad. Alternatively, co-orbital systems can enter one orbit and later adjust it to closely match the target's orbit, overcoming latitude limitations. However, this approach requires more energy, as it involves going into Earth orbit and then changing the orbit, leading to a heavier and more expensive system. The co-orbital ASAT is less likely to be used as an aggressive weapon compared to the direct ascent ASAT. Its launch must be precisely timed with the target satellite's orbit for the ASAT to reach its destination with available fuel. Once in orbit, the co-orbital ASAT must be controlled from the ground, similar to any other satellite [83].

Nuclear Detonation in Space

This type of attack destroys the target with intense radiation. A nuclear device can be transported to the upper atmosphere using any ballistic missile (equipped with the necessary fuel) and detonated at the appropriate location and time. Because the exosphere is a vacuum, satellites cannot be affected by the explosion itself but only by the nuclear radiation, which can travel thousands of kilometers. Depending on the satellite's position relative to the explosion site, radiation can destroy the satellite either due to thermal shock, ionization, or the electromagnetic pulses generated by the satellite's own system (SGEMP = System Generated ElectroMagnetic Pulse).

Thermal shock occurs when the satellite overheats by absorbing X-rays produced by the explosion. However, the most likely scenario involves the destruction of electronic components due to ionization resulting from the penetration of the satellite's thin walls by X-rays. Within a few hundred kilometers, these two phenomena become fatal for unprotected satellites.

At greater distances (more than 1,000 km), the damage will mainly arise from SGEMP. Electromagnetic pulses are negative electric currents created when X-rays release electrons from the satellite's surface. The generated electric current initially causes malfunction and later leads to the destruction of the satellite's electronic parts. However, even satellites not in direct line of sight with the nuclear explosion site may later experience damage from radiation trapped within the Earth's magnetic field [78].

Anti-Satellite (ASAT) Weapons

All existing weapon systems with the potential or inherent ability to target satellites are grounded on Earth. Earth-based Anti-Satellite (ASAT) systems offer key benefits, including larger size, reduced vulnerability, and more cost-effective construction and maintenance compared to space-based alternatives. However, they face drawbacks such as their distance from targets in Geostationary Orbit (GSO) and the challenges posed by Earth's atmosphere. The two main categories of ASATs consist of missiles and directed-energy weapons.

There are two basic versions of ASAT missiles systems the direct ascent ASAT and the ASAT and the co-orbital ASAT, or space mine that is described above. The direct ascent ASAT is pretty much launched as an air-defence or anti-naval missile and the term means that once launched the missile is directed straight to the target using an impact trajectory and not an orbital one.

The technology is well-developed and accessible to numerous nations. However, challenges lie in the guidance and control aspects. Given the short timeframe for the ascent from Earth to Low Earth Orbit (LEO), the missile cannot be directed straight at the target; instead, it must be aimed at an anticipated location where the target is expected to be shortly. Consequently, an ASAT is not launched aggressively at a specific "target."

Upon reaching the proximity of the target, the ASAT must employ a seeker or homing device to acquire and track the target, guiding the ASAT until it reaches a distance close enough for the warhead to achieve the intended effect. An optimal choice for this purpose is likely an infrared sensor capable of detecting the satellite's heat signature against the cold backdrop of space. Once the ASAT is sufficiently near the target, the warhead is triggered [83].

Anti-Satellite Weapons

THREATENING THE SUSTAINABILITY OF SPACE ACTIVITIES

ANTI-SATELLITE (ASAT) WEAPONS are weapons that are designed to deceive, disrupt, deny, degrade, or destroy space systems.



Some ASAT weapons are designed to destroy satellites by hitting them with a high-speed missile, which can produce a massive amount of debris.

The destruction of a single 10-ton satellite can generate:

- 8-14 million objects 1mm-1cm in size
- 250-750,000 objects 1-10cm in size
- 5-15,000 objects >10cm in size

Source: Union of Concerned Scientists

All the Space Debris in Earth's Orbit

Distribution of space debris from all sources, by size and number of objects



The use of destructive ASAT weapons adds to the increasing amount of space debris in Earth's orbit.

Space debris can travel at up to 29,000km/h, posing an active threat to other objects in orbit.

Source: ESA

The Impact of Destructive ASAT Weapons

There are two types of destructive ASAT tests:



Co-orbital

Weapons that are placed into orbit and maneuver close to a target and attack it by various means, including direct collision, fragmentation, or using robotic arms.



Direct-ascent (DA)

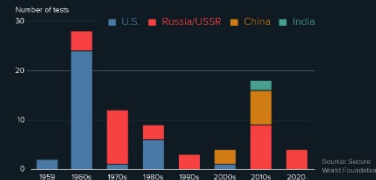
Missiles that are launched from the Earth's surface or from the air to destroy a satellite target.

Types of Direct-ascent ASAT Weapons



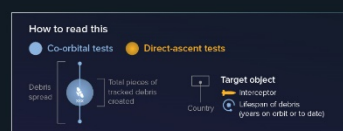
Note: Missiles not shown to scale. Illustration is of the carrier containing the PL-19 missile; no image of Nudol missile is available.

Since 1959, there have been 80 ASAT tests carried out by four countries.

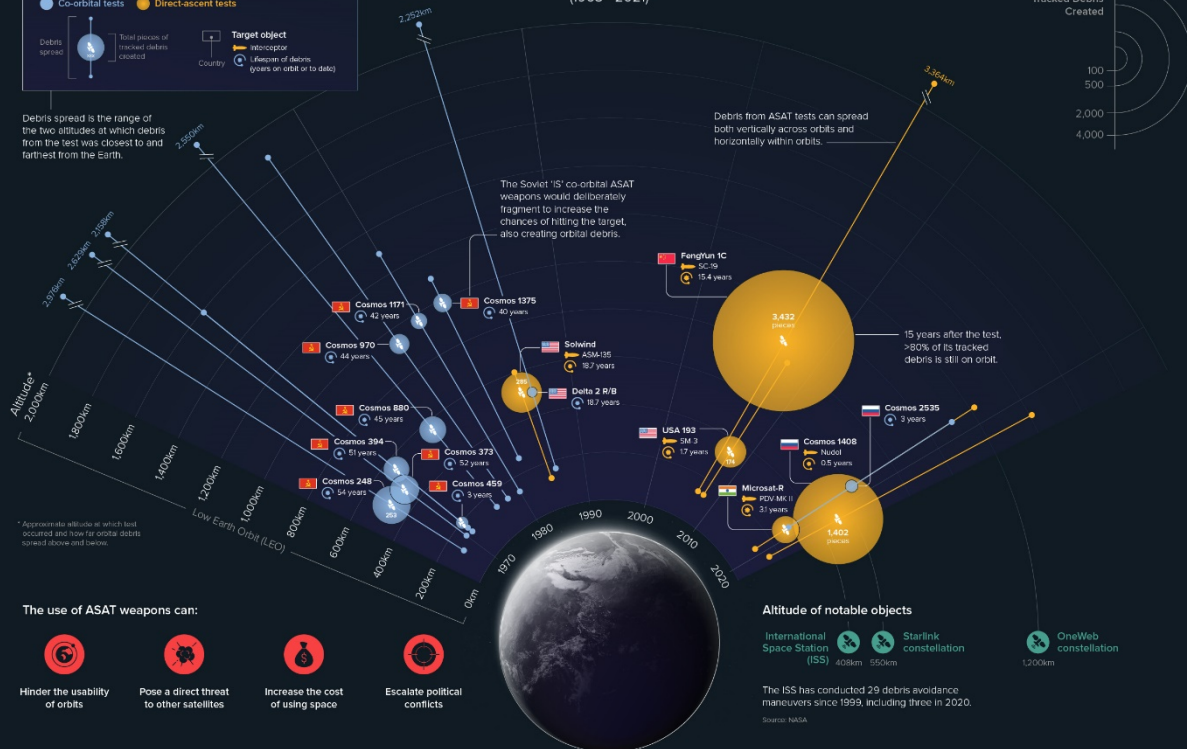


Source: Secure World Foundation

Destructive ASAT tests generate thousands of debris objects that spread across vast distances. Not all the tests depicted above generated debris. Tests with known debris are shown below.



The Spread of Debris from Destructive ASAT Tests (1968 - 2021)



The use of ASAT weapons can:

- Hinder the usability of orbits
- Pose a direct threat to other satellites
- Increase the cost of using space
- Escalate political conflicts

While space has long had military users, it is becoming increasingly commercial and critical for civilian life.

The U.S. was the first country to pledge against conducting destructive ASAT testing to promote responsible behavior in space. As space activity increases, the threat of destructive ASAT tests requires action from countries around the globe.

"These tests, to be sure, are reckless as they are irresponsible. These tests also put in danger so much of what we do in space."

- U.S. Vice-President Kamala Harris

This graphic was produced thanks to the support of the Republic of Korea.

Secure World Foundation promotes cooperative solutions for space sustainability and the peaceful uses of outer space.

For more information about ASAT weapons, visit www.swfound.org for SWF's annual threat assessment.

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Figure 12: Anti-Satellite Weapons

[Source: <https://www.visualcapitalist.com/sp/anti-satellite-weapons/>]

5.2. Unintentional Threats in Space

Natural Hazards can happen from time to time. The main natural hazards affecting space operations are space debris, space weather, and near-Earth objects (Schrogl et al., 2015).

Space debris

The last 60 and more years from the launch of the first artificial satellite, thousands of satellites have been placed in orbit, resulting to the “near” Space, “traffic problem”, as constantly there are thousands of satellites that are orbiting around the Earth. Some of them are fully operational, but the rest are no longer operational.

At first this was not a problem, as the satellites orbiting the Earth were very few, at least until the early 90's, when the International Academy of Astronauts had seemed to be concerned about the arising problem of the space debris, issuing an official Position Paper

Today, however, this innumerable number of satellites has begun to create intense problems, for which, if no drastic action is taken immediately, in the future it is very certain that there will be incalculable consequences both for the safety of operational satellites and for the Earth itself, in case any of these rotating objects end up losing orbit and start falling to the Earth's surface.

All these concerns are now expressed in Kessler Syndrome. This term was first mentioned in 1978, in the publication of the American Astrophysicist Donald Kessler, entitled "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt", where he introduced a topic that has begun to be increasingly concerned the scientific community: space junk. The theory and consequently the term introduced by Kessler is based on the fact that over time (as space missions continue at an increasing rate) the concentration of objects in orbit in space will become greater. This will increase the chances of objects colliding with other objects or satellites, resulting in an increase in the number of these objects but also the problems that will occur, especially in the low Earth orbit, where most inactive satellites and objects are located.

The Low Earth Orbit (LEO) is an area in space that includes all possible orbits at an altitude of less than 2,000 km above the Earth's surface. For example, in such an orbit the International Space Station rotates and in general in this area the orbits of countless satellites are located. In this area there is also "space junk", which are objects that come from inactive satellites. These range in size from a coin to a book, spinning around the Earth at very high speeds. It is estimated that more than 21,000 space objects exist that are larger than 10 cm, and over 500,000 objects exist that are between 1 and 10 cm. Tracking this large number of space objects complicates space situational awareness, and inadvertent collision with space debris is a very real concern [84].

As it turns out, over time the launch of new satellites and their placement in orbit around the Earth is an increasing challenge, as in addition to the necessary calculations to determine and maintain the orbit of a satellite should be calculated and mathematically, the probability of a satellite colliding with some "space junk", the dangers and consequences of such a collision on the mission as well as at what altitude area is most likely to occur.

Kessler syndrome therefore describes the possible continuous collision of "space junk" in low Earth orbit. The idea is that two objects that collide at high speed, break down into

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smaller pieces and fragments, creating more and more "space junk". This process is continuous and has already created major problems as over time, the low earth orbit is going to become an inaccessible area. In other words, in the future, most satellites will have a high probability of colliding with such an object.

According to ESA (European Space Agency) estimates, there are approximately 129 million objects of waste in space, where they move at speeds that allow them to cause great damage. The size of these objects ranges from 1 millimeter (mm) up to several centimeters (cm). As the number of satellites orbiting in low Earth orbit increases exponentially over time, this means that this region will become more and denser.

Finally, in order to limit as much as possible, the increasing volume of "space junk", it is necessary to impose specific restrictions and procedures when launching new missions, but at the same time, possible solutions and methods for removing existing "space debris" are constantly being studied [85].

Since 1968 until 2021, China, India, Russia (former USSR) and USA, have successfully conducted 15 destructive ASAT tests, creating thousands of pieces of tracked debris that spread across vast distances [86].

After Russia's last ASAT test, USA was the first nation to condemn the continuing of ASAT tests, as U.S. Vice President Kamala Harris made the following public statement: *"These tests, to be sure, are reckless as they are irresponsible"*.

Year	Country	Weapon type	Number of tracked debris pieces created	Spread of debris	Lifespan of debris (years on orbit)
1968	USSR	Co-orbital	253	109km-2,976km	54
1970	USSR	Co-orbital	147	137km-2,629km	52
1971	USSR	Co-orbital	117	152km-2,158km	51
1971	USSR	Co-orbital	28	126km-1,603km	3
1976	USSR	Co-orbital	127	126km-2,550km	45
1978	USSR	Co-orbital	72	126km-1,898km	44
1980	USSR	Co-orbital	48	122km-1,304km	42
1982	USSR	Co-orbital	62	247km-1,110km	40
1985	U.S.	Direct-ascent	285	120km-615km	19
1986	U.S.	Co-orbital	18	152km-2,252km	1
2007	China	Direct-ascent	3,432	125km-3,364km	15
2008	U.S.	Direct-ascent	174	123km-803km	2
2019	Russia	Co-orbital	27	279km-1,121km	3
2019	India	Direct-ascent	130	115km-1,233km	3
2021	Russia	Direct-ascent	1,402	148km-1,423km	0.5

Figure 13: Number of tracked debris pieces created by the ASAT tests

[Source: <https://www.visualcapitalist.com/sp/anti-satellite-weapons/>]

Solar wind

As solar wind is defined the stream of electrically charged particles that flow from the Sun's upper atmosphere into the Space. This stream which is being spread constantly to all directions comprised of high-energy plasma (superheated matter – so hot that the electrons are ripped away from the atoms forming an ionized gas). Solar wind is supersonic (average velocity 400 km/s) and thus plasma needs only 4 days to reach from the Sun to Earth.

Of course, solar wind is not negligible towards the satellites. Solar wind's intensity varies in a recurring period of 11 years (solar cycle). In times close to solar cycle's maximum, the Earth's atmosphere heats more and expands, which means that this situation pose risks for LEO satellites, especially these at an altitude lower than 1000 kilometers are more likely to run into air and lose energy lowering their orbits by as much as 30 kilometers, but also it could lead to the burning up of a satellite, like these of SpaceX that were burned up in 2022 after a geomagnetic storm⁶⁶.

In addition, the solar wind has a double nature, the one is slow-moving and the other is fast-moving. The fast – moving solar wind can contain extremely energetic particles that can penetrate the outer casing of a satellite and pass into the electronic chips and disrupt them or even damage the valuable solar panels. Although satellites are shielded with aluminum, this material cannot protect the satellite from every possible particle (some particles travel at 80% of the speed of light), which thankfully are not met often. Moreover, the solar wind makes charge collect on the satellite surface and that can cause another similar issues. In fact, different parts of the satellite accumulate charge unevenly, so there can be observed a high voltage difference between near adjacent surfaces. When satellites, as orbiting, go in and out of shadow they can release the charge they've collected, with similar catastrophic results for the electronics [87].

Celestial bodies

Obviously, taking into account the subject of this thesis and the so far referred topology that is the Near Space, the term celestial body has to deal with small sized celestial bodies, otherwise we would witness such at least destructive hit, that the satellites would be the least of the human concerns.

Such celestial bodies could be meteor showers, small meteoroids – micrometeoroids (varying from 1 mm to 1 meter in size) or ice material from comets tails' passing through earth's orbit plane. It may seem a very small size, but while entering Earth's atmosphere, such bodies have a velocity that varies from 11 km/sec to 73 km/sec, thus making them "lethal" for the satellites. Accordingly, space debris have a velocity varying from 10km/sec to 15 km/sec in LEO. Subsequently, Earth is surrounded by super speed "bullets".

⁶⁶ Piyush Mehta, Solar storms can destroy satellites with ease — a space weather expert explains the science, 24/06/2022, available: <https://www.space.com/solar-storms-destroy-satellites>

5.3. Records from the Cold War USA – CCCP

Having explored the various threats encountered in space, it's crucial to examine how these vulnerabilities can be exploited intentionally. The Cold War era serves as a stark reminder of the potential for weaponization of space capabilities.

Undisputedly, the most discussed and well known period of the modern era, after the end of the World War II, is the Cold War, which was a period of geopolitical tension marked by competition and confrontation between communist nations led by the USSR and western democracies leading by the USA⁶⁷.

This bizarre term was first used by the English writer George Orwell in an article named "You and the Atomic Bomb" published in 1945 to refer to what he predicted would be a nuclear stalemate between "two or three monstrous super-states, each possessed of a weapon by which millions of people can be wiped out in a few seconds."⁶⁸

This period started almost two years after the end of World War II. During the WW of course, the two current superpowers USA and USSR, stood and fought together against the fascists Nazi and their heinous crimes against humanity. Luckily for the humanity, the Allies coalition managed to crush the Third Reich and restore the previous pacific state. However, during the WW II the Allies coalition had been acting mostly according to the ancient proverb "the enemy of my enemy is my friend" and after their win this "friendship" came to an end as well, because, on the one hand the USA was cautious about the communism and the tyrannical rule of Stalin, on the other hand the Soviets were resented with USA refusal to give them a leading role in the international community and of course they were deeply incensed with the delayed entry of USA in WW II, where millions of Russians had lost their life until then⁶⁹.

For the aforementioned reasons, the prevalent sentiment between the superpowers was the distrust and a constant competition about who is more powerful adversary. The term "cold" was used because this competition was never escalated to an open war between the two nations. However, the positions of both superpowers were well known. Specifically USSR believed that with the U.S.A. there can be no permanent *modus vivendi* (agreement between parties that disagree), whereas USA after the WW II believed that the best defence against the USSR was the "long-term, patient but firm and vigilant containment of Russian expansive tendencies"⁷⁰.

The USA's "containment" tactic was focused to the development and gathering of more weapons to their arsenal for precaution against a potential communist expansionism. That is depicted to the fact that apart from the other conventional era weapons, USA encouraged the development of atomic bombs, inaugurating the Atomic Age. Soviets answered by a test bomb and after that USA responded once again with the most destructive hydrogen bombs, and USSR responded as well⁷¹.

⁶⁷ Cold War History, available: <https://www.history.com/topics/cold-war/cold-war-history>

⁶⁸ Cold War international politics, available: <https://www.britannica.com/event/Cold-War>

⁶⁹ Cold War History, loc. cit.

⁷⁰ *ibid*

⁷¹ *ibid*

In general, in the 1950s, the United States and the Soviet Union were actively pursuing advancements in technology. Following World War II, German scientists, who had almost developed the first intercontinental ballistic missile for Nazi Germany, contributed to research efforts in both countries. Additionally, both nations were working on satellite development in alignment with the International Council of Scientific Unions' goal of launching satellite technology by late 1957 or 1958. Throughout the decade, the United States conducted numerous tests on rockets and missiles, all of which proved unsuccessful [88].

But one of the most interesting part of the two superpowers' competition was the Space Race. It was really challenging and prestigious for the first nation to conquer a previously uncharted, dark, inhospitable and uninhabited territory, demonstrating in this way the superiority of its technology and military firepower.

The Arms Race: A competition Fueled by Fear

The arms race refers to a period of intense competition between nations, where the primary focus is on achieving military superiority. This competition involves the development and stockpiling of increasingly powerful weapons, with the ultimate goal of deterring or winning a potential war. During the Cold War (1947-1991), the United States and the Soviet Union engaged in a particularly dangerous arms race, primarily focused on nuclear weapons and ballistic missiles. These weapons have the potential to cause unimaginable devastation, and their stockpiling during the Cold War created a constant state of tension and fear between the two superpowers.

The arms race wasn't limited to just nuclear weapons. Other types of weaponry, such as tanks, fighter jets, and chemical and biological weapons, were also heavily developed and stockpiled during this period. This relentless pursuit of military dominance not only placed a massive strain on the economies of both nations but also increased the risk of accidental conflict, with potentially catastrophic consequences.

Starting from the Arms Race, this was the first and the most intense long “battle” of the Cold War, as on 1949 Soviets exploded their first atomic warhead, so eventually both the big nations had been equipped with atomic bombs and a potential mishandling on either side could wreak havoc on the planet.

The period 1948 – 1953 thus was a peak for the Cold War, as many geopolitical tensions took place all over the world. One of the most characteristics events is the Korean War that started on 25th June 1950, between the Democratic People's Republic of Korea (North Korea) and the Republic of Korea (South Korea), after the invasion of North Korea to South Korea. North Korea was initially allied by Soviet Union and along the way with People's Republic of China, while the UN with the USA as the major participant allied with the South Korea⁷². The Korean War lasted for approximately 3 years and during this period more than 2.5 million people were killed. The Korean War provided the first confrontation between two nuclear powers, but as the war progressed it was clearly depicted how difficult it would be for either side to use atomic bombs decisively in battle [89].

In the same period, Soviets managed to create their own atomic bomb, resulting to the announcement of the then U.S. President Harry Truman about the U.S.A. intention

⁷² Korean War, 1950 – 1953, <https://www.britannica.com/event/Korean-War>

regarding the construction of an even more advanced and destructive thermonuclear weapon, the hydrogen bomb or “superbomb”.

The first hydrogen bomb test, named Ivy Mike⁷³, took place in 1st November 1952 in an atoll named nowadays Enewetak (then named Eniwetok), placed in the Marshall Islands cluster. In this island atomic bomb tests were held in 1948, 1951, 1952, 1954, and 1956⁷⁴. The intensity of the bomb was extremely high (yield of 10 megatons) and it had created an almost 65-square-kilometers fireball that led to an island’s vaporizations whereas it had been calculated that its power could destroy half of the Manhattan [90].

Of course, the Soviets did not leave this fact unanswered. Soon, on 12th August 1953 the Soviet Union made a test on a tower in central Siberia. The bomb design named “Layer Cake”, had been consisting by alternating layers of hydrogen fuel and uranium (yield of 400 kilotons). As may be easily perceived, this hydrogen bomb hybrid was not as powerful as the one that had been exploded by the Americans, however it had an impressive advantage: it had a small size and it could be dropped by an airplane. Two years later, on 22th November 1955, the first Soviet pure hydrogen bomb named RDS-1 had been exploded in the Semipalatinsk test site in northern Kazakhstan [91]. On the later stages, the Soviet constructed bigger and bigger bombs, and particularly on 23th October 1961 at the Novaya Zemlya test site near the Arctic Circle had been exploded by the Soviets the largest bomb ever tested, named Tsar Bomba, or “Emperor of the Bomb” (yield of 58 megatons)⁷⁵.

Apart from the period 1948 – 1953, another intense period of Cold War was in 1958 – 1962. The most important geopolitical event that marked the Cold War and almost a nuclear war was about to burst, was during the Cuban Missile Crisis in October 1962. At this period, both U.S.A. and Soviet Union had already began to develop ICBM and Soviets secretly installed ICBMs in Cuba, in order to be prepared for a potential nuclear attack against U.S.A.

An American U-2 spy plane secretly took photos from the construction of nuclear missile sited in Cuba. President Kennedy after advised properly, placed a naval blockade to the Cuba’s perimeter in order to avoid further Soviet military equipment to reach the island. For two weeks the tension was very immense, but finally the two leaders Kennedy and Khrushchev reached to an agreement. Soviet Union from its side would remove all the ICBMs and dismantle all the sites from Cuba, provided that U.S.A. would not make another invasion to Cuba. Furthermore, this agreement contained another term that had been remained secret for more than 25 years and was about the removal of U.S. nuclear missiles from Turkey [92].

Of course, at these years there had been marked numerous atomic and hydrogen bombs by U.S.A. and U.S.S.R. rising the concerns about of radioactive fallout and environmental contamination. However, it is certain that the Cuban missile crisis demonstrated that neither the United States nor the Soviet Union were willing to use nuclear weapons for fear of retaliation (and consequently mutual nuclear annihilation). This observation led to the signing of the Limited Test Ban Treaty on 5th August 1963 by the U.S.A., U.S.S.R. and U.K., which banned the nuclear weapons tests in the atmosphere, in outer space and under water [93].

⁷³ The Manhattan Project, an interactive history, <https://www.osti.gov/opennet/manhattan-project-history/Processes/BombTesting/yield.html>

⁷⁴ Enewetak atoll, Marshall islands, <https://www.britannica.com/place/Enewetak>

⁷⁵ Khrushchev boasted, “It could have been bigger, but then it might have broken all the windows in Moscow, 4,000 miles away.”

More specifically, the treaty⁷⁶:

- prohibited nuclear weapons tests or other nuclear explosions under water, in the atmosphere, or in outer space
- allowed underground nuclear tests as long as no radioactive debris falls outside the boundaries of the nation conducting the test and
- pledged signatories to work towards complete disarmament, an end to the armaments race, and an end to the contamination of the environment by radioactive substances.

In addition, the White House and the Kremlin, 10 months after the Cuban Missile Crisis established a direct line of communication known as the "Hotline"⁷⁷.

Finally, in the late 1960s and early 1970s, there is a notable improvement in U.S.-Soviet relations, marking the beginning of an optimistic period focused on nuclear arms control. This is exemplified by the Strategic Arms Limitation Talks (SALT). In 1972, the two nations achieve significant milestones with the Anti-Ballistic Missile (ABM) Treaty, restricting the deployment of missile defence systems to their national capital and one ICBM site. Additionally, SALT I is established, placing limits on the number of nuclear missile silos and submarine-launched missile tubes for a five-year duration, however it didn't address strategic bombers or warhead arsenals.

The Space Race: A Race to Stars

The space race, on the other hand, was a period of intense competition between nations focused on achieving milestones in space exploration. This competition took place primarily during the Cold War (1957-1970s) between the United States and the Soviet Union. While the space race had some ties to military advancements, the primary focus wasn't on weaponry. Instead, it centered on technological achievements and pushing the boundaries of human exploration. Major milestones of the space race included launching the first artificial satellite (Sputnik 1 by the USSR in 1957), sending the first human into space (Yuri Gagarin by the USSR in 1961), and landing the first humans on the moon (Apollo 11 by the US in 1969).

The space race, despite its competitive nature, led to significant technological advancements that benefit us today. The development of rockets, satellites, and spacecraft not only allowed us to explore the cosmos but also paved the way for innovations in communication (satellites), navigation (GPS), and weather forecasting. While the arms race was a dangerous period fueled by fear, the space race, although competitive, ultimately led to progress and a deeper understanding of our universe.

The Space Race followed as a separate sector of contest of two rivals, as the Arms Race that had already started more than a decade ago had to deal with creation and testing of atomic, hydrogen and thermonuclear bombs and the development of ICBMs. By the end of WW II, the U.S. clearly appeared to be the world's technology giant. The United States detonated her first atomic bomb in 1945 and her first hydrogen bomb in 1952. Despite this

⁷⁶ Nuclear Test Ban Treaty, <https://www.jfklibrary.org/learn/about-jfk/jfk-in-history/nuclear-test-ban-treaty>

⁷⁷ 1963, Hotline established between Washington and Moscow, <https://www.history.com/this-day-in-history/hotline-established-between-washington-and-moscow>

advantage and the presence of German experienced rocket scientists in the U.S., the Soviet Union quickly made significant advances in rocketry.

The official beginning of the Space Race (one of the greatest milestones for the entire history of human kind) started on 4th October 1957, a bit more than ten years after the beginning of Cold War, when the Soviets made an amazing breakthrough by launching the first ever artificial satellite named “спутник” -Sputnik 1- (which means satellite or more precisely fellow traveler in English).

The satellite was launched successfully from the Baikonur Cosmodrome located in Kazakhstan. Sputnik 1 satellite was a just 58 cm-diameter aluminum sphere that weighted around 85 kilograms⁷⁸. In addition, the satellite had four external antennas orienting to the one side, with around 3 meters length, broadcasting radio pulses. Sputnik 1 had been fully operating for three weeks, until its batteries failed and finally, after 92 days and 1400 completed orbits (1 orbit per 96.2 minutes) the Sputnik fell back to Earth’s atmosphere. During this pioneering mission, Sputnik 1 collected data referring to the density of the upper layers of the atmosphere and the propagation of radio signals in the ionosphere [108].

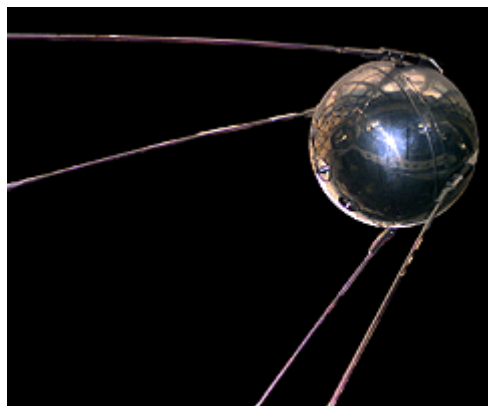


Image 17: Sputnik 1

[Source: <https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1957-001B>]

Apart from this unprecedented historical moment, this also was a severe hit to Americans’ pride, as both of the nations had been struggling in the 1950’s (notably this decade was the peak of the Cold War) towards the conquest of Space and for sure the Americans would not like to stay in a lower level than the Soviets. This moment sparked the Space Race and since then both nations made their best efforts to continue on unprecedented and great achievements in a contest that changed definitely the flow of history.

Meanwhile, the very next big achievement for soviets was the launch of Spuntik 2 on 3rd November 1957, along with the first animal in Space, a dog named Laika^{79 80}. Sputnik 2 completed almost two times the orbits of Sputnik 1, 2.570 in total.

⁷⁸ “The satellite carried a thermometer and two radio transmitters, as part of the Soviet Union’s work during the International Geophysical Year. While its goal was partly scientific, the launch and deployment into orbit had heavy political significance and signaled the country's ambitions in space” – Nick Greene, The Story of Sputnik 1, updated 04/02/2020, available: <https://www.thoughtco.com/sputnik-1-first-artificial-satellite-3071226>

⁷⁹ What was the first animal sent into space?, accessed: 05/11/2023, available: <https://www.rmg.co.uk/stories/topics/what-was-first-animal-space>

⁸⁰ Ibid. Sputnik 2 was equipped with food supplies for a week, an oxygen generator and a heat regulation system. In 1999 several Russian sources reported that most likely Laika died during the fourth orbit of Sputnik 2, after a failure in temperature control.

The first respective response came from the USA two months after the launch of Sputnik 1, on 6th December 1957, however the attempt of launching the first satellite Vanguard TV-3⁸¹ was a complete failure. Almost 4 months later of Sputnik's launch, on 31st January 1958, the Explorer project launched to orbit the satellite Explorer I [95]. Explorer I was launched from Cape Canaveral entering in an orbit with period of 114,8 minutes, perigee 354 kilometers and apogee 2.515 kilometers. The satellite was rocket - shaped, with length of 2,03 meters, diameter 15,9 centimeters and weight 14 kilograms. The satellite was operational until 23th May 1958 and burnt up to Earth's atmosphere on 31st March 1970, after completing 58.000 orbits [96]. In addition, few months later, in July of 1958, the U.S. Congress passed the National Aeronautics and Space Act which was the prelude of the NASA, dedicated to space exploration since the opening of its gates in 1st October 1958 [95].

Of course, the Soviets didn't stop at just sending the first satellite but continued with additional launches, and so the Space Race continued at an extremely intense pace. Following their previous pioneering success, the Soviets launched in 2nd January 1959 the Luna 1, which was the first spacecraft planned to land on the Moon's surface, however finally passed almost 6.000 km away and it went into orbit around the Sun, between the orbits of Earth and Mars⁸². Nevertheless, the next two Luna spacecraft made new achievements, on the one hand Luna 2 that was launched on 12th September 1959 managed to reach the lunar surface, though crushed on the impact, on the other hand Luna 3 that was launched on 4th October 1959 managed to perform an orbit around the Moon and took the first photograph of its dark side. [97]

Continuing on their space superiority, the Soviets on 12th April 1961 sent the first human around Earth. The Soviet cosmonaut Yuri Gagarin, boarding on the spacecraft Vostok 3KA made the first human Earth orbit at 108 minutes. A few days later, on 5th May 1961, the American astronaut Alan Shepard became the first American and the second man that had been sent in Space. Boarding on Mercury – Redstone 3 (MR-3) or "Freedom 7" as was named by Shepard, Alan Shepard made a 15 minutes suborbital flight - a flight that goes into space but does not go all the way around Earth-, at the height of 490 kilometers [98]. The Space Race was on its peak, as both nations had been constantly struggling to achieve new and unbelievable milestones. This could be easily depicted from the fact that three weeks after Shepard's space flight, on 25th May 1961, President John F. Kennedy while giving his famous speech at Rice University stadium, requested from the people of the United States to envisage and support an ambitious goal, declaring: "I believe that this nation should commit itself to achieving the goal, before the decade is out, of landing a man on the moon and returning him safely to Earth."⁸³

Two years later, the Soviets made another resounding response. On 16th June 1963, Valentina Tereshkova, boarding on the spacecraft Vostok 6, becomes the first civilian and first woman in space. This was a joint mission with Vostok 5, launched on 14th June 1963 boarded by the cosmonaut Valery Bykovsky. The closest approach between the two Vostok made during the journey was five kilometers achieved on Vostok 6 first orbit where a radio contact established as well. Tereshkova completed 48 orbits at around 3 days and Bykovsky 82 orbits at around 5 days. The flight objectives encompassed a comparative evaluation of the impact of different space-flight elements on the male and female organisms; study on medical biology; and additional development and enhancement of

⁸¹ more information about this satellite available: https://en.wikipedia.org/wiki/Vanguard_TV-3

⁸² Luna 1, NASA Space Science Data Coordinated Archive, available: <https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1959-012A>

⁸³ Michele Ostovar, The Decision to Go to the Moon: President John F. Kennedy's May 25, 1961 Speech before a Joint Session of Congress, available: <https://www.nasa.gov/history/the-decision-to-go-to-the-moon/>

spacecraft systems during cooperative flight. Just after Gagarin's flight, Korolev came up with the concept to launch a woman into space as yet another first [99].

Literally, from Sputnik 1 launch in 1957 until 1965 the Soviets seem to be invincible in the Space Race, especially after an even more breathtaking event, when on 18th March 1965, the Soviet cosmonaut Alexei Leonov leaves Voskhod 2 spacecraft capsule, in a specialized spacesuit and tethered to it, conducts a 12 minutes spacewalk [100]. Again the Americans are one step behind (less than 3 months), as the American astronaut Ed White left the Gemini 4 spacecraft capsule for a roughly 20 minutes spacewalk on 3rd June 1965.⁸⁴ One month later, on 15th July of 1965 Mariner 4 mission made a successful approach to planet Mars and took the first photos of its surface [101]. However, the Americans had not yet managed to take the lead at Space Race. Few months later, on 3rd February 1966, once again the Soviets reach first another milestone, which was the first successful soft-land on the Moon with the spacecraft Luna 9, while Americans managed to land on the Moon the spacecraft Surveyor 1, four months later [102].

Therefore from December 1957 (Sputnik's launch) until February 1966, the Soviet supremacy is undisputed to the overwhelming majority of the space milestones. However, 11 years after the Space Race inauguration, the Americans cover all the distance and take the competition to another level. This is achieved with the famous Apollo Program. In the beginning, Apollo 8 carries the first humans (Frank Borman, James Lovell and William Anders) and entered lunar orbit on Christmas Eve, 24th December 1968. At this day, the three astronauts had a live broadcast from lunar orbit, showing pictures of Earth and Moon as seen from Apollo 8⁸⁵. The interesting fact about this mission was that until that moment there were some complications with the Lunar Module, so NASA fearing not keeping up with President Kennedy's schedule, sent the Apollo 8 to the Moon without a lunar module [103].

Finally, the most unimaginable, extraordinary milestone, the landing of man on the Moon's surface had been achieved on time, as set by the U.S.A., before the end of 1960's. On 20th July 1969, Michael Collins, an Apollo 11 crew member, continues to orbit the moon while Neil Armstrong and Edwin "Buzz" Aldrin descend on the Moon with the Lunar Module "Eagle", becoming the first men to set foot on the lunar surface and making, as Armstrong stated when touched the lunar surface, "one small step for man, one giant leap for mankind". Subsequently, America was victorious in the Space Race, as evidenced by the broadcast landing that attracted 650 million viewers worldwide [104].

⁸⁴ This day in history: Ed White becomes first American to walk in space, available: <https://spacecenter.org/this-day-in-history-ed-white-becomes-first-american-to-walk-in-space/>

⁸⁵ The astronauts recited passages from Genesis and concluded with a greeting to everyone "on the good Earth" as their command module hovered over the lunar surface, sending back pictures of the moon and Earth. "We were told that on Christmas Eve we would have the largest audience that had ever listened to a human voice," recalled Borman during 40th anniversary celebrations in 2008. "And the only instructions that we got from NASA was to do something appropriate." "The first ten verses of Genesis is the foundation of many of the world's religions, not just the Christian religion," added Lovell. "There are more people in other religions than the Christian religion around the world, and so this would be appropriate to that and so that's how it came to pass."

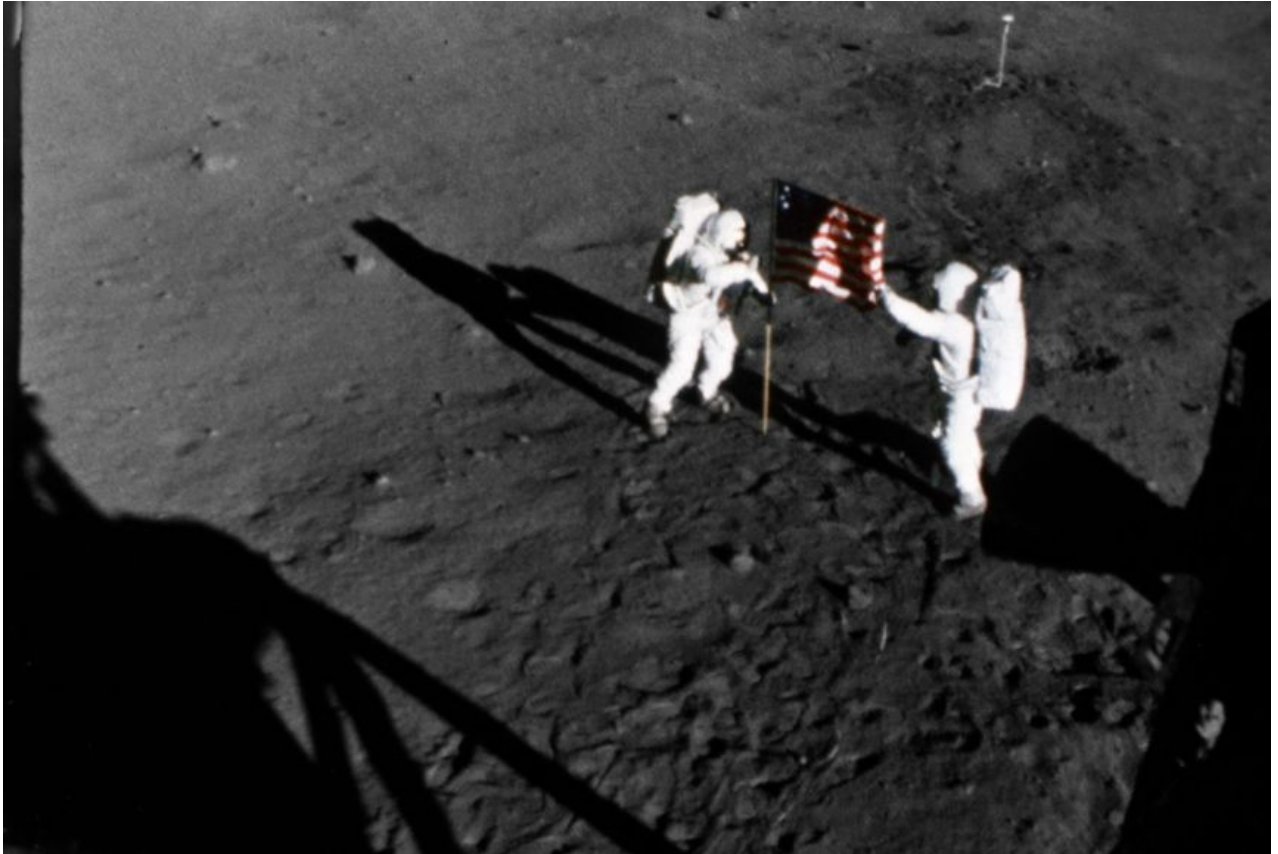


Image 18: Apollo 11 Astronauts on Moon

[Source: <https://education.nationalgeographic.org/resource/history-space-exploration/>]

Most likely, the landing of the first man on the moon after 12 years of the Space Race beginning, marked an informal end to the rivalry between the two superpowers. Indeed, in the early 1970s, the U.S. motivation and goals for further Space conquer dwindled, as well as Soviet Union's respectively.

More specifically, in 1971 the Soviets announced that their interest laid in research on the long-term stay of man in Space. At this direction, in the same year the Salyut program began its activities, launching a number of stations that conducted experiments in space and hosted astronauts from other nations. The U.S.A. followed the Soviet Union's example and in 1973 they also launched the Space Station Skylab, this time without starting a supplementary Space Race. On the contrary, in 1975, Soviet spacecraft Soyuz docked with the U.S. spacecraft Apollo 18, the first-ever international space rendezvous, and the two commanders Tom Stafford and Alexei Leonov exchange the first international handshake. This act can be seen to symbolically end the space race, paving the way for future joint missions, such as the International Space Station and the Shuttle-Mir programme [105].



Image 19: Apollo – Soyuz First Rendezvous

U.S astronaut Thomas P. Stafford and cosmonaut Aleksei A. Leonov seen at the hatchway leading from the Apollo Docking Module to the Soyuz Orbital Module during the Apollo-Soyuz Test Program mission.

[Source: <https://www.nasa.gov/history/the-apollo-soyuz-test-project-success-achieved-for-first-rendezvous-and-docking-of-two-nations-spacecraft-in-space/>]

The Cold War, with its intense political, military, and ideological dimensions, profoundly influenced the space sector. The Space Race, a product of Cold War competition, not only showcased remarkable achievements like the Moon landing but also highlighted the militarization of space. The legacy of the Cold War in the space sector is complex, encompassing technological advancements, international cooperation, and the ongoing evolution of space exploration in a more multipolar and commercialized world. As was reflected on this era, it is essential to recognize both the remarkable achievements and the challenges posed by the intersection of geopolitics and the cosmos [106].

PART D. EMERGING DYNAMICS AND LEGAL FRAMEWORKS IN SPACE SECURITY

The advent of the space age has heralded unprecedented opportunities and challenges, reshaping the geopolitical landscape and redefining the parameters of global security. As humanity ventures deeper into the cosmos, the dynamics of space security have become increasingly complex and multifaceted. This evolving domain is marked by the rapid advancement of technology, the proliferation of state and non-state actors, and the burgeoning commercial space sector.

The contemporary landscape of Space Security, is full and promising of new and more emerging threats and strategic considerations. Furthermore, it delves into the critical role of international law and diplomacy in maintaining peace and security in outer space through "Securing the High Frontier: International Law and Space Diplomacy." These chapters collectively offer a comprehensive analysis of the dynamic interplay between technological advancements and the legal frameworks governing space activities, underscoring the necessity for collaborative efforts to secure the high frontier.

6. The New Landscape of Space Security Challenges

Space activities, which has already mentioned, have started soon after the burst of Cold War and almost 70 years later, have enormously been accelerated in the 21st century. Space becomes a new promising area of expansion, and we entered to the "Space Race 2.0", a race that continues more intensely than ever. But this time, it seems to be a different kind of race, as the private industries are the leading actors. The noticeable difference lies in the fact that three very important variables have been added to the equation "Space".

The first variable is the involvement of more national actors. Comparing to the actors of the Cold War that were only the great superpowers U.S.A. and U.S.S.R., even until 20 years ago, nowadays it is feasible for a wide group of countries from different continents to be active in the space sector, either independently or as part of a coalition or an international organization (e.g. ESA).

The second variable has to deal with the involvement of the private industry, meaning that during the Cold War the main adversaries were governments, whereas nowadays have emerged many private companies, start-ups, entrepreneurs, academic institutions and public sector users oriented to scientific research and commercial endeavor that have entered the realm of space sector.

One of the most important component of the private space industry is SpaceX⁸⁶ (Space Exploration Technologies Corporation), a space transportation and aerospace manufacturer founded in 2002 by Elon Musk. In 2006, this company developed a delivery vehicle named Dragon, and soon after the Falcon rocket, designed to launch humans and payload into orbit. Since then, SpaceX achieved many accomplishments, including the manufacture of Starship, a spaceship that is designed for missions at planet Mars.

⁸⁶ SpaceX, accessed: 19/01/2023, available: <https://www.techtarget.com/whatis/definition/SpaceX>
G. - E. Giataganas

The rival awe, Blue Origin⁸⁷ is an aerospace manufacturer and provides sub-orbital to orbital spaceflight services. The company was founded in 2000 by Jeff Bezos and its expertise deals with the development of orbital technology, as well rocket - powered VTVL vehicles for the suborbital and orbital space. Apart other activities, in 2019 the company revealed plans for a moon lander, called Blue Moon, which is a robotic cargo and lander design concept for delivering cargo to the Moon⁸⁸.

The third variable has to do with the present activities performed in space compared to the past traditional ones which had to do with weather prediction, intelligence gathering and spy on adversaries terrains and facilities. In recent years, the space industry—where global competitiveness is accelerating the most—has become more visible. In quest of new prospects, visionary nations and private entrepreneurs have found space research and high-tech products and services that are becoming more and more important in aviation appealing. These include space tourism, space mining, space communication, satellite and rocket technologies, and space research [107].

Furthermore, the space sector is entering a new era marked by unprecedented opportunities and challenges. Navigating these challenges requires a concerted effort from governments, space agencies, private companies, and the international community. Addressing issues such as space debris, sustainability, cybersecurity, regulation, and human health will be essential for the continued progress of space exploration and developments to relevant performed activities. As humanity extends its reach into the solar system for the moment, collaboration and innovation will be the keys to overcoming these challenges and unlocking the full potential of the space sector in the 21st century. Below there is a description about the aforementioned issues.

6.1 Sustainable Space Exploration

As humanity ventures further into space, the focus has shifted from short-term missions to establishing a sustainable presence. This section explores the challenges of Sustainable Space Exploration, such as resource utilization and waste management. These challenges are crucial for long-term space security, as they impact the viability and resilience of space programs.

Indeed, almost seven decades have passed after the launch of the first artificial object passing the Kármán Line⁸⁹, both the human technology and ambition made a huge progress. The private sector made a great contribution towards this direction as for example Elon Musk, the chairman of SpaceX has envisioned the colonization of the planet Mars until 2029⁹⁰. At the moment, the implementation of this ambition seems to be something very distant, though there are less distant and more feasible missions such as the colonization of the Moon that are planned from governmental organizations and private industries in the next few decades.

⁸⁷ Blue Origin. Archived from the original on December 6, 2013, available:

<https://web.archive.org/web/20131206013801/http://blueorigin.com/>

⁸⁸ Jeff Bezos Unveils Blue Origin's Vision for Space, and a Moon Lander, accessed: 19/01/2023, available:

<https://www.nytimes.com/2019/05/09/science/jeff-bezos-moon.html>

⁸⁹ The Kármán Line: Where space begins, <https://www.astronomy.com/space-exploration/the-karman-line-where-does-space-begin/>

⁹⁰ Elon Musk hints at a crewed mission to Mars in 2029, <https://www.npr.org/2022/03/17/1087167893/elon-musk-mars-2029>

The sustainability of space exploration hinges on a comprehensive approach that addresses environmental, economic, and social factors to ensure that space activities can continue without significant harm to space and Earth environments or the depletion of resources vital for both the human factor and the mission's wholeness. Addressing these constant emerging challenges involves several key strategies, including the development of reusable technologies, resource utilization in space, mitigation of space debris, international cooperation and governance, economic sustainability, advanced life support systems, and consideration of ethical and societal impacts.

Getting started, the development of reusable technologies, such as SpaceX's Falcon rockets, significantly reduces the cost and environmental impact of space missions. By refurbishing and reusing parts of the spacecraft, the need for manufacturing new rockets for every mission decreases, leading to substantial savings in both resources and expenses. Reusability not only makes space exploration more economical but also lessens the carbon footprint associated with frequent launches [108].

In addition, the future utilization of resources found on the Moon, Mars, or asteroids, known as In-Situ Resource Utilization (ISRU), could greatly reduce the need to launch materials from Earth, thereby lowering costs and the environmental impact of launches. ISRU practice includes extracting water for drinking and fuel or mining materials for construction, which can significantly support long-term missions and habitation. So, this approach promotes self-sufficiency and reduces dependency on Earth-based resources [109].

Another crucial key strategy for the sustainability of space exploration is the mitigation of space debris, as debris already poses a significant threat to both current and future missions. Effective strategies for minimizing debris creation and actively removing existing debris could ensure safer space operations and protect valuable assets in orbit. Thus, implementing policies and technologies for debris reduction is essential for maintaining a sustainable space environment [110].

Of course, it is necessary to take into account how vital is the international cooperation and governance for the sustainable use of space. Global cooperation can lead to the development of standardized practices and policies, managing space traffic, and mitigating environmental impacts, through international treaties, agreements, and collaborative projects, countries can share knowledge, resources, and responsibilities, ensuring that space activities benefit all of humanity [111].

In addition, economic sustainability and innovative funding models, such as public-private partnerships, help share the financial burden and risks of space exploration. These models foster innovation and ensure continuous investment in space technologies, making space exploration more economically viable. Sustainable economic strategies are key to maintaining momentum in space exploration initiatives [112].

Moreover, considering ethical and societal impacts is also critical for sustainable space exploration. This involves protecting extraterrestrial environments and assessing potential impacts on human societies. Developing ethical frameworks and policies ensures that space activities are conducted responsibly and benefit humanity as a whole [113].

One of the most important key strategies is the development of advanced life support systems that recycle air, water, and waste are essential for long-duration missions. These systems sustain the crew while reducing the amount of supplies needed from Earth, enhancing the sustainability of space missions. Efficient life support systems are fundamental for the viability of extended space habitation and exploration [114].

Regardless the venture, it is for certain that the sustainability of each of these potential programs should be taken into extremely careful consideration, as their execution and fulfillment will require long-term viability of the space exploration endeavors. For instance, a series of microbial biotechnologies uniquely suited to establish sustainable processes for ISRU and loop-closure. Towards this direction, in addition to the traditional mechanical, physical and biological approaches, the use of microorganisms would enable the long-term life-support and habitat systems' performance. Thus, it could be supported the removal of carbon dioxide from the colony's atmosphere and channeled to other vital procedures, such as food biomanufacturing. In addition, several types of waste, such as human metabolic end-products, could be upcycled using microorganisms [115].

Furthermore, when a mission will target this venture, it is really crucial to this one way trip to select the most suitable and necessary materials from Earth to the space base. Logistics, added to the aforementioned procedure is a "nightmare" as parameters such as cost, weight and maximum load capacity should be added to the equation. For sure, pioneering 3D printing and recycling technologies in space are the key combined with the respect and the preservation of the new environments [116].

Achieving sustainability in space exploration requires a multifaceted approach involving technological innovation, international cooperation, ethical considerations, and economic models. By focusing on reusability, resource utilization, debris mitigation, and comprehensive governance, humanity can ensure that space activities are both responsible and enduring. The combined efforts in these areas will pave the way for a sustainable and prosperous future in space exploration.

6.2 Cybersecurity Concerns

We already mentioned the growing involvement of private companies in space exploration. This increased reliance on space infrastructure introduces new security challenges, particularly in the realm of Cybersecurity Concerns. A successful cyberattack on space assets could have a devastating impact, disrupting critical services or even escalating conflicts.

Although Space is some hundreds kilometers above our head, if we really think about it, it is constantly interacting with our typical daily life. Indeed, one large variety of infrastructures that provide constant services to us is in orbit, meaning the satellites that are responsible for global communication, navigation (e.g. GPS), Internet, weather prediction etc. So, a cyber-attack on a space infrastructure could have devastating effects on everyone on the ground.

In general, a cyber-attack is a set of actions performed by mostly unknown actors, whose purpose is to gain unauthorized access, steal/remove data or cause damage to computers and infrastructures. The potential entry points for cyberattacks encompass the antennas on satellites, ground stations, the landlines linking ground stations to terrestrial networks, and the user terminals connecting to satellites. These cyber intrusions can serve various purposes, including monitoring data traffic patterns (identifying communicating users), surveilling the actual data, or injecting fabricated or corrupted data into the system. Although executing cyberattacks demands a profound comprehension of the targeted systems, it does not necessarily mandate substantial resources for deployment.

A cyber-attack can be launched from any location connected to Internet, by an individual or a contracted private group or a group using one or more tactics, techniques and procedures (TTPs)⁹¹. It must be noted that year by year the global cost of cyber-attacks is increased with a large rate, in fact the global economy hit record numbers in 2022 by reaching 546 billion dollars and is projected to climb another 41% over the next five years⁹².

It is easily perceived that cybersecurity will be a key factor for the upcoming space exploration as the astronauts' safety and the proper functioning of the satellite and computer systems will be of high priority in order an operation to be successful. Thus, one of the most concerned space cybersecurity threat is going to be the hacking and compromise of spacecraft and satellites.

In general, cybercriminals try to exploit vulnerabilities or to contrive ways to compromise computer systems in order to gain their control and perform malicious actions, which means that a state or non-state actor that lacks internal cyber capabilities pose a cyber threat. Thus, the space cybersecurity threat does not differ somehow from a typical one performed in computer infrastructures on Earth.

Regarding the space systems, a cybercriminal would intend to take control of vital systems, limit technically the capabilities of these systems or granting access to sensitive satellite data. A cyber assault on space systems has the potential to lead to data loss, extensive disruptions, and the permanent loss of a satellite. For instance, if an adversary gains control of a satellite by launching a cyberattack on its command and control system, the consequences could involve shutting down all communications and causing permanent harm to the satellite. This harm may include depleting its propellant supply or causing damage to its electronics and sensors. Attributing a cyberattack accurately and promptly can be challenging, if not impossible, as attackers employ various methods to conceal their identity, including the use of hijacked servers to launch their attacks [117].

For instance, in the Ukraine War jamming and other types of cyberattacks were used against the Starlink SpaceX terminal [118]. An adding concern to the space cybersecurity is that the most space station and were built many years ago meaning that they are highly complex but also highly vulnerable to cyber-attacks, so the space industries have to invest in robust cybersecurity measures accordingly.

Apart from the few of the aforementioned potential ways of performing a cyber-attack the cybersecurity concerns that are related to space challenges have to be noted, as they are multifaceted and significant due to the increasing dependence on space-based systems for critical infrastructure and commercial activities.

Some of the key cybersecurity concerns are the following:

- **Vulnerability of Space Systems:** Many space systems, including satellites and ground stations, were designed before cybersecurity became a top priority. This makes them vulnerable to various cyber threats, including command intrusions, payload control attacks, and denial-of-service attacks. Such vulnerabilities can lead to the loss of

⁹¹ What Is a Cyber Attack?, <https://www.imperva.com/learn/application-security/cyber-attack/>

⁹² Space Cybersecurity: Exploring Challenges, and Opportunities, <https://www.sangfor.com/blog/cybersecurity/space-cybersecurity-exploring-challenges-and-opportunities>

mission data, reduced lifespan of space assets, or even complete control loss, potentially causing collisions and generating harmful orbital debris [119], [120], [121].

- **Interconnected Technologies:** The reliance on interconnected technologies and networks in the space sector presents multiple vulnerabilities that hackers can exploit. These include cyberattacks on satellite communications, terrestrial jamming of receivers, and spoofing or hacking of communication networks used by space segments. As the number of satellites and the complexity of their operations increase, the attack surface expands, making cybersecurity increasingly challenging [120], [121].
- **Commercialization of Space:** The rapid commercialization of space activities has intensified cybersecurity concerns. Market incentives to reduce costs and innovate quickly often result in compromised software and hardware security. This commercial expansion increases the risk of cyber espionage, data theft, and other malicious activities targeting space-based assets [120], [122].
- **Geopolitical and Military Risks:** Nations like China and Russia emphasize exploiting cyber and space domains to support their economic and military objectives. This raises concerns about asymmetric warfare through cyberattacks on space systems, making space a new operational domain for military activities. The legal and diplomatic challenges of regulating space activities further complicate the cybersecurity landscape [119], [120].
- **Standardization and Policy Challenges:** The lack of standardized cybersecurity measures for private companies operating in space poses significant risks. While efforts are being made to develop standards and best practices, such as NASA's Space Security Best Practices Guide and the US Space Force's cybersecurity standards, there is still a need for comprehensive international cooperation and regulatory frameworks to address these issues effectively [120], [121].

Responding effectively to these cybersecurity concerns requires a well-designed approach that includes technological innovations, robust governance policies, and international cooperation. In addition, efforts to enhance the security of space missions must keep pace with the evolving cyber threats to ensure the protection of valuable data and technology in the increasingly digitalized space environment [119], [121], [122].

6.3 Regulation and Space Traffic Management

The influx of new actors in space, as mentioned in the introduction, necessitates the development of proper guidelines. This section explores the challenges of Regulation and Space Traffic Management. With more countries and private companies launching objects into space, coordinating these activities and preventing collisions becomes critical for long-term space security.

The surge in commercial space activities has prompted the need for enhanced regulation and space traffic management, as the launching missions are getting increased year by year. However, coordinating the increasing number of satellites and spacecraft to prevent collisions and ensure responsible use of orbital slots is a complex task. International cooperation is essential to establish clear guidelines and protocols for space traffic

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management, preventing overcrowding in orbit and minimizing the risk of collisions that could generate additional space debris⁹³.

In general, Space Traffic Management (STM) refers to the means and rules for accessing orbital areas and outer space, carrying out activities there and returning in a safe, sustainable, and secure way. This field has become a priority issue due to the constant increase of satellites and debris in space (more than 1 million pieces of debris larger than 1 cm are currently orbiting the Earth), while the next decade thousands of satellites are going to be launched in orbit expecting the problem to get even worse [112]. For sure, the coordination of the increasing number of satellites and spacecraft in orbit poses a complex challenge and the taken measures for effective space traffic management are crucial to prevent collisions and maintain the overall sustainability of space activities.

In addition, as the private sector explores the potential for resource extraction from celestial bodies, questions arise about the environmental impact and responsible resource utilization. The absence of clear guidelines for extraterrestrial resource exploitation poses ethical and environmental challenges that must be addressed to ensure sustainable space exploration.

Lastly, the development of a robust regulatory framework is also one of the primary challenges posed by the intense presence and activities of private sector in space is. Unlike government space agencies, private companies operate in a competitive environment where the race to market often outpaces regulatory adaptation. Private companies may prioritize their immediate goals over long-term space sustainability, potentially contributing to an increase in orbital debris. Balancing economic interests with the need for sustainable space practices is a challenge that needs careful consideration.

The challenges of STM are multifaceted, encompassing legal, technical, and coordination issues, as following: [124]

- **Legal Challenges:** The existing space law framework is fragmented and outdated, struggling to keep up with the rapid increase in space activities and the number of actors involved. The lack of a unified international regulatory body makes it difficult to enforce consistent standards globally.
- **Technical Challenges:** Managing the increasing number of satellites and debris in Earth's orbit requires advanced SSA capabilities. Current technologies and methods for tracking space objects and predicting collisions are insufficient given the high volume and velocity of these objects. The 2019 incident where a ESA satellite had to manually avoid a collision with a Starlink satellite highlights the limitations of current STM systems.
- **Coordination Challenges:** Effective STM necessitates global cooperation among governments, private companies, and international organizations. The diversity of stakeholders, each with different priorities and resources, complicates efforts to develop a cohesive STM framework. Moreover, geopolitical tensions can hinder the sharing of critical data and coordination efforts required for effective STM.
- **Economic and Operational Challenges:** The commercial space sector's growth, including ventures like space tourism, adds to the congestion in space, increasing the

⁹³ Kyriakopoulos, G. (2017). Space Traffic Management as a sine qua non prerequisite for the sustainability of outer space activities: Evaluating Regulatory Patterns Provided by the Airspace Paradigm. Presentation at the 2017 IACO-UNOOSA Workshop.

risk of collisions. As launch costs decrease, the number of satellites and space missions increases, necessitating more robust and proactive STM policies to manage traffic and mitigate debris.

In summary, addressing the challenges of STM requires a comprehensive, collaborative approach that integrates legal reforms, advanced technologies, and international cooperation to ensure the sustainable and safe use of outer space.

6.4 Human Health in Long-Duration Space Missions

We highlighted the growing focus on space exploration, particularly long-duration missions. Ensuring the Human Health in Long-Duration Space Missions is crucial for the success of these endeavors. While not a traditional security challenge, astronaut health can be a national security concern if a medical emergency arises during a deep space mission.

As the ambitions for human exploration of Mars and other celestial bodies expand, it becomes crucial to comprehend and address the health hazards linked to prolonged space missions. Prolonged exposure to factors such as microgravity, radiation, psychological stress, and limited resources presents substantial challenges to the overall well-being of astronauts. Investigating advanced life support systems, medical technologies, and psychological support mechanisms is imperative to guarantee the health and safety of astronauts undertaking extended space missions

Space travel by its nature hides a lot of unique dangers and awesome challenges, focusing the major priority of the overall safety and well-being of the crew throughout the mission duration. If anyone thinks about it, it is really bizarre to travel in a relative small spacecraft into the unknown and inhospitable Space, where if something goes really wrong there is no escape route. Astronauts pass through a very extensive physical and mental training however no human being can totally surpass the primitive instincts of survival and self-maintenance.

Until now, the largest distance that human kind has travelled outside Earth was until Moon, a fraction of the desired and future distance that the space missions will include. Thus, it is easily well taken that the challenges for the human health during these missions will be a separate mission.

The primary health hazards associated with spaceflight encompass elevated levels of detrimental radiation, gravitational field alterations, extended periods of isolation and confinement, the constraints of a closed and potentially inhospitable living environment, and the stress induced by being far from Earth. Each of these threats introduces distinct physiological and performance risks to the crew, requiring thorough characterization and effective mitigation. Since crew members encounter these stressors concurrently, it is essential to consider their combined impact on human physiology and performance. The concept of a "space exposome" provides a comprehensive framework that captures the interplay of all environmental influences on the human body. When integrated with individual genetics, this exposome shapes the outcomes of space travel on the human system [125].

More specifically, the human health faces numerous challenges during long-duration space missions. These challenges can be broadly categorized into physiological, psychological, and environmental factors.

Physiological Challenges

Microgravity Effects: Prolonged exposure to microgravity leads to significant muscle atrophy and bone density loss, as the absence of gravitational force reduces the stress on bones and muscles. Countermeasures such as resistance exercises are critical but not completely preventive [126].

Cardiovascular Health: Microgravity also impacts cardiovascular health, causing fluid shifts towards the upper body, which can lead to increased intracranial pressure and vision problems. This condition, known as Spaceflight-Associated Neuro-Ocular Syndrome (SANS), is a significant concern [127].

Radiation Exposure: Outside the protection of Earth's magnetosphere, astronauts are exposed to higher levels of cosmic radiation. This exposure increases the risk of cancer, central nervous system effects, and degenerative diseases such as cataracts and cardiovascular disease [128].

Immune System Dysregulation: Space travel can alter immune function, making astronauts more susceptible to infections and potentially affecting the body's ability to deal with injuries and diseases. Changes in the gut microbiome due to altered gravity and diet also play a role in this immune dysregulation⁹⁴.

Psychological Challenges

Isolation and Confinement: The psychological stress of prolonged isolation and confinement in a spacecraft can lead to mood disorders, depression, and anxiety. Effective coping strategies and mental health support are crucial for maintaining psychological well-being [128].

Sleep Disruption: The lack of a natural day-night cycle in space often disrupts circadian rhythms, leading to sleep disorders. Poor sleep quality can impair cognitive function and overall health, necessitating careful management of the sleep environment and possibly the use of pharmacological aids [127].

Environmental Challenges

Closed-Loop Life Support Systems: Ensuring a sustainable and safe supply of air, water, and food is challenging in a closed-loop system. Contamination and technical failures pose serious risks to astronaut health and mission success⁹⁵.

⁹⁴ The Space Environment on Human Health and Disease,
https://www.mdpi.com/journal/life/special_issues/space_microbiome

⁹⁵ *ibid*

Microbial Risks: The closed environment of a spacecraft can lead to the proliferation of harmful microorganisms, which can pose infection risks. Maintaining strict hygiene protocols and monitoring microbial growth are essential [126] [128].

In summary, long-duration space missions pose significant challenges to human health that require comprehensive countermeasures and ongoing research to mitigate. Understanding these challenges is crucial for the future of human space exploration. For further reading, you can refer to the studies and reviews available in sources like Nature, MDPI, and Oxford Academic.

Already and for the last 50 years, Human Research Program (HRP) has studied what happens to the human body in space. Currently, NASA intends to conduct additional dedicated and prolonged research on the space station. These studies aim to provide insights into the adaptations of the human body to the spaceflight environment over varying extended durations. Such knowledge is crucial for the success of future deep space missions.

Finally, NASA is investigating the hazards associated with Mars missions, categorizing them into five human spaceflight risks based on the stressors they impose on the body. These risks can be succinctly described using the acronym "RIDGE," representing Space Radiation, Isolation and Confinement, Distance from Earth, Gravity fields, and Hostile/Closed Environments [129].

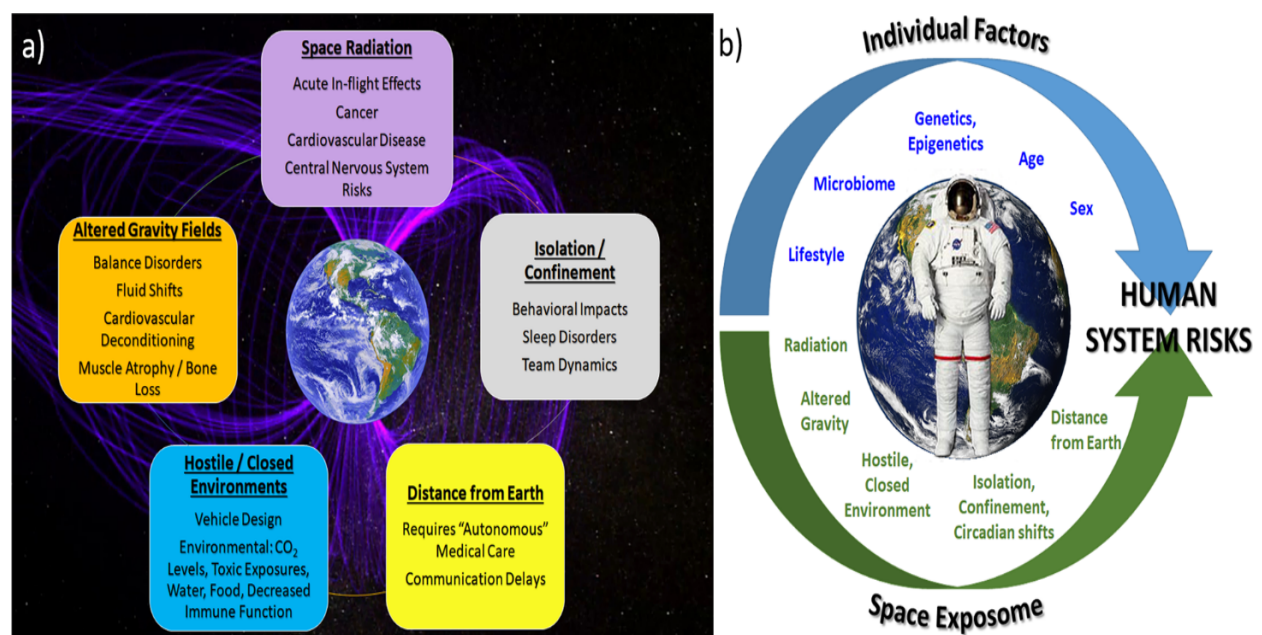


Figure 14: The five main hazards of spaceflight and the space exposome

[Source: <https://www.nature.com/articles/s41526-020-00124-6/figures/1>]

7. Securing the High Frontier: International Law and Space Diplomacy

The influx of new players in space, necessitates diplomatic efforts to ensure peaceful exploration and avoid a competitive and potentially conflictual environment in space. This section explores the ongoing diplomatic efforts to avoid a competition in space through organizations like COPUOS and international treaties.

Clearly affected by the Cold War and potential devastating consequences, the interested countries and governments have already they have put diplomatic channels into action since the Cold War period in order to avoid the competition and a potential new Cold Era. It is essential though to note that the space domain is dynamic, and geopolitical developments can impact diplomatic efforts. For this reason, continuous dialogue and cooperation are crucial for maintaining stability and preventing a competitive and potentially conflictual environment in space.

7.1 Committee on the Peaceful Uses of Outer Space

The key impact to the peaceful use of Space has the Committee on the Peaceful Uses of Outer Space (COPUOS). It is a United Nations committee that plays a crucial role in promoting international cooperation in the peaceful use and exploration of outer space. COPUOS was established by the United Nations General Assembly in 1959 and began its work in 1962. The committee is composed of member states that discuss and make recommendations on various aspects of space-related activities. It serves as a forum for the exchange of information and ideas, facilitates international cooperation in space exploration, and contributes to the development of international space law. Furthermore, it covers a broad range of topics, including the legal and policy framework for outer space activities, the use of space technology for sustainable development, and the prevention of an arms race in outer space. COPUOS also oversees the work of two subcommittees: the Scientific and Technical Subcommittee and the Legal Subcommittee, which delve deeper into technical and legal aspects of space activities, respectively⁹⁶.

7.2 Outer Space Treaty

We could consider the Bible of Space Diplomacy the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, or for the sake of brevity the Outer Space Treaty (OST), which, adopted in 1967, is considered a key international agreement that establishes principles for the use of outer space. Described by the official United Nations Office for Outer Space Affairs, as "the cornerstone of international space law" the OST specifically, it prohibits the placement of nuclear weapons in orbit and the militarization of celestial bodies and so far many countries have been parties to this treaty⁹⁷.

The Treaty was opened for signature by the three depository Governments (the Russian Federation, the United Kingdom and the United States of America) in January 1967, and it entered into force in October 1967. The Outer Space Treaty provides the basic framework on international space law, including the following principles [130]:

- the exploration and use of outer space shall be carried out for the benefit and in the interests of all countries and shall be the province of all mankind;
- outer space shall be free for exploration and use by all States;

⁹⁶ <https://www.unoosa.org/oosa/en/ourwork/copuos/index.html>

⁹⁷ <https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html>

- outer space is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means;
- States shall not place nuclear weapons or other weapons of mass destruction in orbit or on celestial bodies or station them in outer space in any other manner;
- the Moon and other celestial bodies shall be used exclusively for peaceful purposes;
- astronauts shall be regarded as the envoys of mankind;
- States shall be responsible for national space activities whether carried out by governmental or non-governmental entities;
- States shall be liable for damage caused by their space objects; and
- States shall avoid harmful contamination of space and celestial bodies

In this Treaty, the rules that had begun to take shape through the decisions of the United Nations General Assembly find their completion. These rules include principles such as the principle of Freedom for exploration and exploitation of outer space, in accordance with international law and for the benefit and interest of all states in the international community. The principle prohibits any form of appropriation and projection of sovereign rights in space. Additionally, it emphasizes the demilitarization of space, the Moon, and other celestial bodies [2]. As of August 2023, 114 countries are parties to the OST, while another 22 have signed it but not yet have completed ratification⁹⁸.

7.3 Supplementary Agreements and Conventions

In general, the OST established an institutional framework the expansion of which becomes possible through subsequent contractual texts in a planned manner and within the limits set by the principles it formulates [131]. More specifically⁹⁹:

- in 1968 was implemented the Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (ARRA) with main points:
 - Rescue of Astronauts: The Agreement emphasizes the obligation of states to take all possible steps to rescue and provide assistance to astronauts in distress. It specifies that the state responsible for the space object involved shall, upon request, furnish the necessary information to facilitate the rescue.
 - Return of Astronauts: The Agreement stipulates that astronauts should be safely and promptly returned to the launching state in case of an emergency landing or rescue operation. The state responsible for the space object is required to ensure the return of astronauts, and the receiving state must cooperate in facilitating this return.
 - Return of Objects Launched into Outer Space: The Agreement addresses the return of space objects launched into outer space. It states that space objects and components thereof must be returned to the launching state, regardless of whether the launch was by a state or a non-governmental entity, in the event of an emergency or if it poses a threat to people, property, or the environment.
- in 1972 was implemented the Convention on International Liability for Damage Caused by Space Objects (Liability Convention) with main points:

⁹⁸ Outer Space Treaty, https://en.wikipedia.org/wiki/Outer_Space_Treaty

⁹⁹ More information available at the website of United Nations Office for Outer Space Affairs (UNOOSA), https://www.unoosa.org/pdf/publications/ST_SPACE_11_Add1_Rev1E.pdf

- Definition of Space Objects: The convention defines "space objects" as including satellites, manned and unmanned spacecraft, and any other object launched into space.
 - Absolute Liability: The Liability Convention establishes the principle of absolute liability for spacefaring nations. This means that a launching state is held liable for any damage caused by its space objects, regardless of fault.
 - Scope of Liability: The liability extends to damage caused on Earth or to aircraft in flight. It covers both damage to states and their nationals.
 - Exempted Activities: The convention exempts certain activities from absolute liability, such as acts of war and military activities during peacetime. However, these activities remain subject to the general principles of international law.
 - Financial Limitation of Liability: While the launching state is held absolutely liable, there is a limitation on the total liability amount. The convention sets a maximum limit of liability for each launching state, and the actual amount is determined by the international community through an international fund.
- in 1975 was implemented the Convention on Registration of Objects Launched into Outer Space (Registration Convention) with main points:
 - Registration Requirement: The convention requires that countries launching objects into outer space must register certain information about those objects with the United Nations. The registered information includes the name of the launching state, an appropriate designator for the space object, the date and location of launch, basic orbital parameters, and general function of the satellite or space object.
 - Obligations of Launching States: The responsibility for registering a space object lies with the launching state. The launching state is required to provide the registration information to the UN Secretary-General promptly after their launch. If there are any changes to the information provided during the registration process, the launching state is obligated to promptly as well inform the UN Secretary-General about these changes.
 - Access to Registration Information: The convention specifies that the registration information is to be made available to all interested parties, ensuring transparency in space activities. States that are not parties to the Registration Convention are still entitled to the benefits of access to the registration information, provided they adhere to the principles set forth in the convention.
 - International Cooperation: The convention encourages international cooperation in the peaceful use of outer space and the exchange of information about space activities.
 - and in 1979 was implemented the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (Moon Agreement), with main points:
 - Common Heritage of Mankind: One of the central principles of the Moon Agreement is the idea that the Moon and its resources are the common heritage of all mankind. It encourages international cooperation and the sharing of benefits derived from the Moon's resources.
 - Prohibition of National Appropriation: The treaty explicitly states that no country can claim sovereignty over the Moon or any part of it. National appropriation of celestial bodies is prohibited, and the Moon is to be used for peaceful purposes.
 - International Management of Lunar Resources: The Moon Agreement envisions an international regime for the management of lunar resources, with the goal of preventing any one nation or entity from exploiting the Moon's resources for its exclusive benefit. It suggests the establishment of an international framework to govern resource extraction and utilization.

- **Sharing Benefits:** The treaty emphasizes the principle of sharing the benefits derived from lunar resources, promoting cooperation in lunar exploration and exploitation. This includes the sharing of scientific knowledge and any economic gains.
- **Environmental Protection:** The Moon Agreement calls for measures to be taken to prevent the disruption of the lunar environment and to avoid any harmful changes to the Moon that could affect its scientific or cultural value.

7.4 International Space Station (ISS) Collaboration

The principles enshrined in international law and diplomacy are not merely abstract concepts, but have very real-world applications that foster cooperation in space exploration. A prime example of this is the International Space Station (ISS) Collaboration.

One of the greatest accomplishments of that century was the International Space Station, mostly because of the ideals it upheld. It represented the hope for a post-Cold War world, the legacy of USSR-US space collaboration, and the idea that space is humanity's common inheritance. A generation of youth was taught by the I.S.S. that space was a place where everyone belonged and where all nations could unite despite their differences and arguments back on Earth. [132].

The International Space Station (ISS) is a large spacecraft that orbits Earth at an average altitude of approximately 420 kilometers (about 261 miles). It serves as a microgravity and space environment research laboratory where scientific research is conducted in astrobiology, astronomy, meteorology, physics, and other fields. The ISS is a collaborative effort involving space agencies from multiple countries and is a symbol of international cooperation in space exploration. Countries such as the United States, Russia, Europe, Japan, and Canada work together on the ISS, setting a positive precedent for collaborative space endeavors.



Image 20: International Space Station

[Source: <https://www.nasa.gov/international-space-station/space-station-facts-and-figures/>]

CONCLUSION

In conclusion, this MSc thesis has undertaken a comprehensive exploration of the intricate and interconnected realms of Earth orbits, satellites, and their multifaceted roles in defence, security, and the challenges posed to space security. The organized structure of the thesis allowed for a systematic examination of critical components, with each chapter contributing valuable insights to the overarching theme.

In Part A, the thesis began by elucidating the various Earth orbits, detailing their types, operational purposes, and the significance of constellations. The discussion then shifted to satellites, providing an in-depth understanding of their systems, subsystems, and different types based on size and operational mission. The importance of satellites in defence and security sectors was underscored, emphasizing their roles in communication, weather prediction, navigation, Earth observation, and military applications.

Part B delved into the use of satellites for defence purposes, offering an exhaustive analysis of their contributions to reconnaissance, early warning, command and control, targeting accuracy, espionage, military communication, and target surveillance. Real-world case studies, such as the Persian Gulf War, the Yugoslavia case, the armed conflict in Afghanistan, and the second Iraq war, exemplified the practical applications of satellite technology in military operations.

Continuing the exploration, Part B further examined the utilization of satellites for security purposes, emphasizing their roles in borders surveillance, environment monitoring, humanitarian aid, and search and rescue operations. The thesis highlighted the versatility of satellite technology in addressing a spectrum of security challenges and enhancing disaster response capabilities.

In Part C, the focus shifted to the security of space itself. The classification of space weapons, including kinetic energy weapons, directed energy weapons, electronic warfare, space mines, traps, and anti-satellite weapons, was elucidated. The discussion extended to threats such as space debris, solar wind, and celestial bodies, drawing attention to the potential risks posed to space security. Historical records from the Cold War, detailing the arms and space race between the USA and CCCP, provided context for contemporary challenges.

The thesis concluded by addressing new challenges in the space sector, including sustainable space exploration, cybersecurity concerns, regulation, and space traffic management, as well as human health considerations in long-duration space missions. Diplomatic efforts to prevent a competitive race in space were explored, highlighting initiatives such as the Committee on the Peaceful Uses of Outer Space, the Outer Space Treaty, supplementary agreements, conventions, and collaboration through the International Space Station.

In summary, this thesis has comprehensively examined the dynamic landscape of Earth orbits, satellites, and the complex interplay between security from and to space. The findings contribute to the broader understanding of the strategic implications of satellite technology and its pivotal role in shaping the present and future of space exploration and security.

ABBREVIATIONS

(in alphabetical order)

3D	Three Dimensional
ABM	Anti-Ballistic Missile
AI	Artificial Intelligence
AOCS	Attitude and Orbit Control System
ARRA	Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space
ASAT	Antisatellite weapon
ASAT	Anti-SATellite
BMEWS	Ballistic Missile Early Warning System
C2	Command and Control
CCD	Charge Coupled Device
COMINT	Communications Intelligence
COPUOS	Committee on the Peaceful Uses of Outer Space
COSPAS	Cosmicheskaya Sistema Poiska Avariynyh Sudov
CSO	Commandante Spatiale Optique
CSS	Civil Security from Space Programme
DEW	Directed Energy Weapons
DSP	Defence Support Program
ELINT	Electronic Intelligence
ESA	European Space Agency
EU	European Union
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
GEO	Geostationary Orbit
GEOSAR	Geostationary Orbiting Search And Rescue
GLONASS	Global'naya Navigatsionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSO	Geo – synchronous Orbit
HAF	Hellenic Air Force
HARM	High-Speed-Anti-Radiation Missile
HEO	Highly Elliptical Orbit
HRM	Human Research Program
ICAO	International Civil Aviation Organization
ICBM	InterContinental Ballistic Missile
ICO	Intermediate Circular Orbit

IMINT	Image Intelligence
IRNSS	Indian Regional Navigation Satellite System
ISR	Intelligence, Surveillance and Reconnaissance
ISRU	in situ resource utilization
ISS	International Space Station
ITU	International Telecommunication Union
KH	Kennen “Keyhole-class”
LEA	Law Enforcement Agency
LEO	Low Earth Orbit
LEOSAR	Low-Earth Orbiting Search And Rescue
MCC	Mission Control Center
MEO	Medium Earth Orbit
MEOSAR	Medium-altitude Earth Orbiting Search And Rescue
MILSATCOM	MILitary SATellite COMmunications
NATO	North Atlantic Treaty Organization
NATO	North Atlantic Treatment Organization
NavIC	Navigation Indian Constellation
NCSA	National Center of Space Applications
NCSR	National Center of Space Researches
NOAA	National Oceanic and Atmospheric Administration
NUDET	Nuclear Detonation Detection
OECD	Organization for Economic Co-operation and Development
OPS	Orbital Piloted Station
OST	Outer Space Treaty
PGM	Precision Guided Missiles
PNT	Positioning Navigation and Timing
PO	Polar Orbit
POES	Polar Orbiting Environmental Satellites
QZSS	Quasi-Zenith Satellite System
RF	Radio Frequency
SALT	Strategic Arms Limitation Talks
SAR	Synthetic Aperture Radar
SAR *	Search and Rescue
SARSAT	Search and Rescue Satellite Aided Tracking
SATCOM	SATellite COMmunications
SBIRS	Space-Based Infrared System
SDA	Space Domain Awareness
SGEMP	System Generated ElectroMagnetic Pulse
SIGINT	Signal Intelligence

SLAM	Standoff Land Attack Missile
SSA	Space Situational Awareness
SSN	Space Surveillance Network
SSO	Sun – synchronous Orbit
SSPI	Society of Satellite Professionals International
STM	Space Traffic Management
TCP	Technical Capabilities Panel
TDRSS	Tracking and Data Relay Satellite System
TELINT	Telemetry Intelligence
TLAM	Tomahawk
TT&C	Telemetry, Tracking, and Command
UN	United Nations
UNOOSA	United Nations Office for Outer Space Affairs
USA	United States of America
USSR	Union of Soviet Socialist Republics
VSAT	Very Small-Aperture Terminal
VTVL	Vertical Takeoff and Vertical Landing
WMAP	Wilkinson Microwave Anisotropy Probe
WW	World War

*written in italic font style to be discriminated from the term SAR (Synthetic Aperture Radar)

APPENDIX I

This appendix refers to countries and organizations and their respective satellites (in total and military) as appeared in October 2023, both active and inactive.

ALGERIA	ALG	6
ARAB SATELLITE COMMUNICATIONS ORGANIZATION	AB	15
ARGENTINA	ARGN	44
ASIA SATELLITE TELECOMMUNICATIONS COMPANY (ASIASAT)	AC	8
AUSTRALIA	AUS	38
AZERBAIJAN	AZER	2
BANGLADESH	BGD	1
BELARUS	BELA	2
BOLIVIA	BOL	1
BRAZIL	BRAZ	21
BULGARIA	BGR	5
CANADA	CA	82
CHILE	CHLE	5
CHINA/BRAZIL	CHBZ	3
COMMONWEALTH OF INDEPENDENT STATES (FORMER USSR)	CIS	1550
CZECH REPUBLIC (FORMER CZECHOSLOVAKIA)	CZCH	4
CZECHIA	CZ	2
DENMARK	DEN	10
ECUADOR	ECU	2
EGYPT	EGYP	10
ESTONIA	EST	2
EUROPEAN ORGANISATION FOR THE EXPLOITATION OF METEOROLOGICAL SATELLITES	EUME	10
EUROPEAN SPACE AGENCY	ESA	93
EUROPEAN TELECOMMUNICATIONS SATELLITE ORGANIZATION	EUTE	56
FRANCE	FR	93
FRANCE/GERMANY	FGER	2
FRANCE/ITALY	FRIT	2
GERMANY	GER	75
GLOBALSTAR	GLOB	84
GREECE	GREC	3
HUNGARY	HUN	3
INDIA	IND	110
INDONESIA	INDO	18
INTERNATIONAL MOBILE SATELLITE ORGANIZATION (INMARSAT)	IM	20
INTERNATIONAL SPACE STATION	ISS	5
INTERNATIONAL TELECOMMUNICATIONS SATELLITE ORGANIZATION	ITSO	87
IRAN	IRAN	4
IRAQ	IRAK	1
ISRAEL	ISRA	36
ITALY	IT	47
JAPAN	JPN	204
KAZAKHSTAN	KAZ	8
KENYA	KEN	1
KUWAIT	KWT	2
LAOS	LAOS	1
LATVIA	LTV	1
LITHUANIA	LTU	10
LUXEMBOURG	LUXE	20
MALAYSIA	MALA	9

MEXICO	MEX	14
MOROCCO	MA	2
NETHERLANDS	NETH	10
NEW ICO	NICO	1
NEW ZEALAND	NZ	10
NIGERIA	NIG	5
NORTH ATLANTIC TREATY ORGANIZATION	NATO	8
NORWAY	NOR	16
O3B NETWORKS	O3B	20
ORBCOMM	ORB	41
PAKISTAN	PAKI	6
PEOPLE'S REPUBLIC OF CHINA	PRC	643
PERU	PER	2
PHILIPPINES (REPUBLIC OF THE PHILIPPINES)	RP	3
POLAND	POL	7
PORTUGAL	POR	2
QATAR	QAT	1
REGIONAL AFRICAN SATELLITE COMMUNICATIONS ORGANIZATION	RASC	2
REPUBLIC OF RWANDA	RWA	2
REPUBLIC OF SLOVENIA	SVN	3
REPUBLIC OF TUNISIA	TUN	1
SAUDI ARABIA	SAUD	15
SEA LAUNCH	SEAL	1
SINGAPORE	SING	19
SINGAPORE/TAIWAN	STCT	2
SLOVAKIA	SK	1
SOCIETE EUROPEENNE DES SATELLITES	SES	66
SOUTH AFRICA	SAFR	7
SOUTH KOREA	SKOR	32
SPAIN	SPN	47
SWEDEN	SWED	12
TAIWAN (REPUBLIC OF CHINA)	ROC	18
THAILAND	THAI	14
TURKEY	TURK	20
TURKMENISTAN/MONACO	TMMC	1
UNITED ARAB EMIRATES	UAE	15
UNITED KINGDOM	UK	653
UNITED STATES	US	6947
UNITED STATES/BRAZIL	USBZ	1
URUGUAY	URY	1
VENEZUELA	VENZ	3
VIETNAM	VTNM	3
TOTAL SATELLITES	ALL 91	11495

Table: Satellites by country and organization (as by October 2023)

[Source: <https://www.n2yo.com/satellites/?c=&t=country>]

country	Military Satellites Total (until 2023)	Military Satellites Other Uses (until 2023)	Military Satellites Shared With Other Countries (until 2023)
United States	239	6 Civil/Military, \n1 Government/Military, \n35 Military/Commercial	1 w/ Sweden
China	140	50 Military/Government	
Russia	105	32 Military/Commercial	
France	18	1 Government/Military	2 w/ Italy, \n2 w/ Italy/Belgium/Spain/Greece
Italy	13	1 Government/Military, \n1 Civil/Military, \n1 Military/Commercial, \n5 Military/Government	2 w/ France, \n2 w/ France/Belgium/Spain/Greece
Israel	11	4 Military/Commercial	
India	9		
Germany	7		
United Kingdom	6		1 w/ United States
Spain	6	1 Government/Commercial/Military, \n1 Military/Commercial, \n1 Military/Government	2 w/ France/Italy/Belgium//Greece
Australia	4	3 Civil/Military, \n1 Military/Commercial	
Mexico	3	1 Government/Military	
United Arab Emirates	3	2 Military/Commercial	
Japan	2	1 Commercial/Military	
Turkey	2		
Thailand	2		
South Korea	2	1 Military/Commercial	
Belgium	2		2 w/ France/Italy/Spain/Greece
Greece	2		2 w/ France/Italy/Belgium/Spain
Brazil	1	1 Commercial/Military	
Egypt	1	1 Military/Commercial	
Iran	1		
South Africa	1		
Colombia	1		
Canada	1		
Chile	1	1 Government/Military	
Sweden	1		
Denmark	1		
Norway	1		
Qatar	1	1 Military/Commercial	
Luxembourg	1	1 Government/Military	

Table: Military Satellites by country (as by October 2023)

[Source: <https://worldpopulationreview.com/country-rankings/military-satellite-by-country>]

APPENDIX II

The last half century of the first millennia, regarding the Space sector, was truly brilliant. In such accumulated time and in a short time after two World Wars, the greatest nations at that time, mobilized and recruited all available resources and achieved the impossible. The following milestones and achievements, even nowadays with all the expanding rise of technology, machine learning, artificial intelligence etc, not more than 80 years since the beginning of the Space Age, seem remarkable.

Below are referred the most important space related achievements of U.S.A. and U.S.S.R. during the Cold war period, including 2 missions of ESA the late 1980s'.

Significant milestones in space exploration			
date accomplished	event	details	country or agency
Oct. 4, 1957	first artificial Earth satellite	Sputnik 1	U.S.S.R.
Nov. 3, 1957	first animal launched into space	dog Laika aboard Sputnik 2	U.S.S.R.
Sept. 14, 1959	first spacecraft to hard-land on another celestial object (the Moon)	Luna 2	U.S.S.R.
Oct. 7, 1959	first pictures of the far side of the Moon	Luna 3	U.S.S.R.
April 1, 1960	first applications satellite launched	TIROS 1 (weather observation)	U.S.
Aug. 11, 1960	first recovery of a payload from Earth orbit	Discoverer 13 (part of Corona reconnaissance satellite program)	U.S.
April 12, 1961	first human to orbit Earth	Yury Gagarin on Vostok 1	U.S.S.R.
Dec. 14, 1962	first data returned from another planet (Venus)	Mariner 2	U.S.
June 16, 1963	first woman in space	Valentina Tereshkova on Vostok 6	U.S.S.R.
July 26, 1963	first satellite to operate in geostationary orbit	Syncom 2 (telecommunications satellite)	U.S.
March 18, 1965	first space walk	Aleksey Leonov on Voskhod 2	U.S.S.R.
July 14, 1965	first spacecraft pictures of Mars	Mariner 4	U.S.
Feb. 3, 1966	first spacecraft to soft-land on the Moon	Luna 9	U.S.S.R.

April 24, 1967	first death during a space mission	Vladimir Komarov on Soyuz 1	U.S.S.R.
Dec. 24, 1968	first humans to orbit the Moon	Frank Borman, James Lovell, and William Anders on Apollo 8	U.S.
July 20, 1969	first human to walk on the Moon	Neil Armstrong on Apollo 11	U.S.
Sept. 24, 1970	first return of lunar samples by an unmanned spacecraft	Luna 16	U.S.S.R.
Dec. 15, 1970	first soft landing on another planet (Venus)	Venera 7	U.S.S.R.
April 19, 1971	first space station launched	Salyut 1	U.S.S.R.
Nov. 13, 1971	first spacecraft to orbit another planet (Mars)	Mariner 9	U.S.
Dec. 2, 1971	first spacecraft to soft-land on Mars	Mars 3	U.S.S.R.
Dec. 3, 1973	first spacecraft to fly by Jupiter	Pioneer 10	U.S.
July 17, 1975	first international docking in space	Apollo and Soyuz spacecraft during Apollo-Soyuz Test Project	U.S., U.S.S.R.
July 20, 1976	first pictures transmitted from the surface of Mars	Viking 1	U.S.
Sept. 1, 1979	first spacecraft to fly by Saturn	Pioneer 11	U.S.
April 12–14, 1981	first reusable spacecraft launched and returned from space	space shuttle Columbia	U.S.
Jan. 24, 1986	first spacecraft to fly by Uranus	Voyager 2	U.S.
March 13, 1986	first spacecraft to make a close flyby of a comet nucleus	Giotto at Halley's Comet	European Space Agency
Aug. 24, 1989	first spacecraft to fly by Neptune	Voyager 2	U.S.
April 25, 1990	first large optical space telescope launched	Hubble Space Telescope	U.S., European Space Agency

[Source: <https://www.britannica.com/science/space-exploration/Major-milestones>]

APPENDIX III

The material presented to this Appendix is not related strictly with the Space Sector, but rather listed in order to stress two major determinant key-points:

- The human factor plays the most critical role in decisions that need to be made within a few seconds, regardless of the advanced technology now at its disposal.
- No matter how advanced a technological system is, the likelihood of error may be extremely reduced, but it can never be completely eliminated.

Thus, appearances can be deceiving... literally!

FALSE ALARM!

THE BALLISTIC MISSILE Early Warning System (BMEWS) performed well for over three decades. However, during the Initial Operating Capability (IOC) phase in the fall of 1960, it generated a high-level threat warning report that was an incident of great concern to the Defense Command Staff.

On 6 September 1960, the Thule, Greenland, BMEWS site began generating warning reports at the lowest threat level that rapidly escalated up to the maximum level. It automatically sent a series of messages warning of an impending missile attack to the North American Air Defense Command (NORAD) in Colorado Springs, Colorado. Before alerts could be sent to the President and dispatched to the Strategic

Air Command bombers, the alerts had to be validated by means of a direct telephone conversation between Command Center personnel and the radar site. An Air Force captain at the site asked for time to perform a check on the radar because he believed it was malfunctioning. He temporarily turned off the transmitter in the sector that was generating the alarms and noted that the echoes ceased. He correctly inferred that the echoes were caused by reflections from the Moon; a hostile missile threat did not exist. The great power and aperture of the BMEWS radar allowed it to detect reflections from the Moon, which was 384,400 km away.

In December 1960, a Lincoln Laboratory team was sent to Thule to investigate a number of

issues related to the IOC, including the Moon echoes. The BMEWS contractor, Radio Corporation of America, had proposed a low-perigee test that eliminated most but not all of the false-alarm conditions attributed to Moon echoes. A member of the Lincoln Laboratory team recognized that simply changing the operating frequency of the radar about every two seconds (less than the round-trip Earth-Moon travel time) could unconditionally eliminate the Moon echoes. This recommendation was presented to the Commander of the North American Air Defense Command on 20 January 1961 and implemented in the radar in conjunction with other improvements. The Moon ceased to be a source of false alarms.

Figure: Storyline of a false alarm

[Source: STONE AND BANNER, Radars for the Detection and Tracking of Ballistic Missiles, Satellites and Planets, Radars for the Detection and Tracking of Ballistic Missiles, Satellites, and Planets, Melvin L. Stone and Gerald P. Banner, VOLUME 12, NUMBER 2, 2000 LINCOLN LABORATORY JOURNAL]

Below follows a part of a journalistic article, for an incident that could lead to the World War III, due to a false ICBM alert:

« On September 26, 1983, the planet came terrifyingly close to a nuclear holocaust.

The Soviet Union's missile attack early warning system displayed, in large red letters, the word "LAUNCH"; a computer screen stated to the officer on duty, Soviet Lt. Col. Stanislav Petrov that it could say with "high reliability" that an American intercontinental ballistic missile (ICBM) had been launched and was headed toward the Soviet Union. First, it was just one missile, but then another, and another, until the system reported that a total of five Minuteman ICBMs had been launched.

"Petrov had to make a decision: Would he report an incoming American strike?" my then-colleague Max Fisher explained. "If he did, Soviet nuclear doctrine called for a full nuclear retaliation; there would be no time to double-check the warning system, much less seek negotiations with the US."

Reporting it would have made a certain degree of sense. The Reagan administration had a far more hardline stance against the Soviets than the Carter, Ford, or Nixon administrations before it. Months earlier President Reagan had announced the Strategic Defence Initiative (mockingly dubbed "Star Wars," a plan to shoot down ballistic missiles before they reached the US), and his administration was in the process of deploying Pershing II nuclear-armed missiles to West Germany and Great Britain, which were capable of striking the Soviet Union. There were reasons for Petrov to think Reagan's brinkmanship had escalated to an actual nuclear exchange.

But Petrov did not report the incoming strike. He and others on his staff concluded that what they were seeing was a false alarm. And it was; the system mistook the sun's reflection off clouds for a missile. Petrov prevented a nuclear war between the Soviets, who had 35,804 nuclear warheads in 1983, and the US, which had 23,305.

A 1979 report by Congress's Office of Technology Assessment estimated that a full-scale Soviet assault on the US would kill 35 to 77 percent of the US population — or between 82 million and 180 million people in 1983. The inevitable US counterstrike would kill 20 to 40 percent of the Soviet population, or between 54 million and 108 million people. The combined death toll there (between 136 million and 288 million) swamps the death toll of any war, genocide, or other violent catastrophe in human history. Proportional to world population, it would be rivaled only by the An Lushan rebellion in eighth-century China and the Mongol conquests of the 13th century.

And it's likely hundreds of millions more would have died once the conflict disrupted global temperatures and severely hampered agriculture. International Physicians for the Prevention of Nuclear War put the potential death toll from starvation at about 2 billion».

[Source: 40 years ago today, one man saved us from world-ending nuclear war, Dylan Matthews, 26/09/2023, available: <https://www.vox.com/2018/9/26/17905796/nuclear-war-1983-stanislav-petrov-soviet-union>]

APPENDIX IV

This Appendix includes some sources that I had the chance to locate during my thesis research, and, at least from my point of view, could be very useful and interesting for an interested reader, from historical, informative and encyclopedic aspect.

Encyclopedia Astronautica → <http://www.astronautix.com/index.html>

The Encyclopedia Astronautica (1997-2019 @Mark Wade) is no longer actively maintained, however its abundant base with thousands of pages contains a plethora of space information and data.

Spacecraft Encyclopedia → <http://claudelafleur.qc.ca/Spacecrafts-index.html>

As mentioned in the above cyber-encyclopedia “This website tries to present the most comprehensive views of all spacecraft ever launched (successfully or not) sponsored by every governments, organizations and corporations since October 1957. With more some 7,500 spacecraft...”

eoPortal → <https://www.eoportal.org/satellite-missions>

As mentioned in the above cyber-portal, there is a Satellite Missions catalogue with information “about past, operational and future missions in the Satellites Missions database, which offers an extensive list of articles about spaceborne EO missions and sensors”. In addition, the tab named Other Space Activities contains information “about other space related activities, including airborne sensors, astronomy, human spaceflight, technology development and much more”.

ORBITING NOW active satellite orbit data → <https://orbit.ing-now.com/#main>

As mentioned in the above website, anyone can use it “to browse active Satellite information derived from TLE* orbit data and other public domain resources”.

*more information about TLE: <https://ensatellite.com/tle/>

UNIDIR (United Nations Institute for Disarmament Research) → <https://unidir.org/>

As mentioned in the above website” UNIDIR is an autonomous institution within the United Nations that conducts independent research on disarmament and international security issues”. Regarding Space Security, “UNIDIR’s Space Security Programme builds knowledge and awareness of the risks and global security implications relating to the space domain”.

TS2 SPACE → <https://ts2.space>

The above website contains a blog with a plethora of articles and news oriented to space security and defence.

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