Spaceworthiness: the future of space products safety

Spaceworthy: o futuro da segurança dos produtos espaciais

La aeronavegabilidad: el futuro de la seguridad de los productos espaciales

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ABSTRACT
The new space race, now played by several private companies and remarkable Asian new players, raises new considerations regarding the fair, enjoyable, sustainable, and economically feasible use of space products and their environment: the planet’s atmosphere and outer space. Inspired by the successful (but not easy nor cheap) path coursed by aviation, this article seeks to present a brief history of both industries (air and space) and the available legal framework for space matters in Brazil, Europe, the USA, and at the United Nations level. Lastly, this work discusses the necessity of creating an organization at the molds of ICAO (International Civil Aviation Organization) in the space sector to promote standardization and harmonization among players all around the globe involved in space operations.

Keywords: Spaceworthiness, Safety, Space Products.
RESUMO
A nova corrida espacial, agora disputada por várias empresas privadas e novos atores asiáticos notáveis, suscita novas considerações em relação ao uso justo, agradável, sustentável e economicamente viável de produtos espaciais e seu ambiente: a atmosfera e o espaço exterior do planeta. Inspirado pelo caminho bem-sucedido (mas não fácil nem barato) percorrido pela aviação, este artigo procura apresentar uma breve história de ambas as indústrias (ar e espaço) e o quadro legal disponível para assuntos espaciais no Brasil, na Europa, nos EUA e ao nível das Nações Unidas. Por último, este trabalho aborda a necessidade de criar uma organização nos moldes da ICAO (Organização da Aviação Civil Internacional) no setor espacial para promover a normalização e a harmonização entre os atores envolvidos em operações espaciais em todo o mundo.

Palavras-chave: Spaceworthy, Segurança, Produtos Espaciais.

RESUMEN
La nueva carrera espacial, que ahora juegan varias empresas privadas y notables nuevos actores asiáticos, plantea nuevas consideraciones con respecto al uso justo, agradable, sostenible y económicamente factible de los productos espaciales y su medio ambiente: la atmósfera del planeta y el espacio exterior. Inspirado por el camino exitoso (pero no fácil ni barato) que recorre la aviación, este artículo busca presentar una breve historia de ambas industrias (aérea y espacial) y el marco legal disponible para asuntos espaciales en Brasil, Europa, Estados Unidos y a nivel de las Naciones Unidas. Por último, en este trabajo se analiza la necesidad de crear una organización en los moldes de la OACI (Organización de Aviación Civil Internacional) en el sector espacial para promover la estandarización y armonización entre los actores de todo el mundo involucrados en las operaciones espaciales.

Palabras clave: Espacionavegabilidad, Seguridad, Productos Espaciales.

1 INTRODUCTION

On October 23, 1906, the Brazilian Alberto Santos-Dumont revolutionized the aviation world with his 14-Bis. Santos-Dumont flew about 60 meters at a height of about 3 meters with a heavier-than-air, manned, 3-axis controllable machine and, most importantly, with the power generated by its own propulsion system [1]. There are, notably, several other claims of creators of the machine we now know by the name of airplane [1]. However, other competitors for this milestone used rails, catapults, and/or exaggeratedly favorable wind conditions to successfully remove their equipment from the
ground [2]. Indeed, it was a Brazilian who accomplished this achievement for the first time in front of a crowd of more than a thousand people and the Official Commission of the Aero Club of France, one of the few recognized bodies in the world capable of homologating such a stunt at that time [3].

About forty years later, the world, especially the armed forces of the leading military powers, was impressed with the relevance that air vectors imprinted on the results of the greatest battles ever fought by humanity during the second world war. It was precisely because of such importance that the aircraft entered a production scale never witnessed before. Despite all the hardships, the war usually leverages the development of many technologies. It could not be different with aviation [4].

While Europe was torn apart by bombings and shootings, commercial aviation was experiencing its spring in America. A considerable passenger and freight transport network were established, with substantial growth potential. However, several technical and political obstacles threatened the flourishing of this new economic sector. The US government, therefore, extended an invitation to 55 allied nations to participate in the most significant international civil aviation conference ever held until that year: 1944. This US initiative was the most critical milestone for creating a global context of mutual recognition and harmonization of safety requirements for the operation of commercial aircraft. That conference went down in history as the famous Chicago Convention [5], whose agreement culminated in creating the ICAO - International Civil Aviation Organization, based in Montreal, Canada.

The main objective of ICAO, from that time until today, is to help States reach the highest possible degree of uniformity in the regulations, standards, procedures, and organization of civil aviation [5]. The outcomes of this international cooperation work are remarkable. Thanks to ICAO standardization [6] and the work of the aeronautical certification authorities, it is possible nowadays to take a flight over Europe on the “wings” of an American airline company and in an aircraft manufactured in Brazil.

In addition to the enormous advantages for the civil aviation business, these are far from the main contributions of the aeronautical certification activity to society. Its primary values reside in the safety of operations and the preservation of human lives. The
primary purpose of airworthiness requirements is to prevent aircraft accidents from being repeated due to the same design flaws [7].

The most explicit demonstration of the impact of aeronautical certification on the safety of civil aviation air operations can be seen in Figures 1 and 2 from the latest Statistical Summary of Commercial Jet Airplane Accidents, published annually by Boeing [8], focusing on the scenario of US and Canadian operators.

Figure 1. Annual ratio of fatal accidents in commercial jet aircraft between 1959 and 2021.

Figure 2. Annual ratio of fatal accidents in commercial jet aircraft between 2002 and 2021.
We came from a ratio of almost fifty accidents per million takeoffs in the late 1950s to less than five accidents per million takeoffs in the 1980s. To get an idea of what this represents, considering the volume of air traffic today, fifty accidents per million takeoffs would mean at least one fatal aircraft accident per week covered in the news. It would be implausible to encourage passengers to take such a risk; consequently, commercial aviation would not be the successful business case we know today. In the early 2000s, we were already living in a scenario of less than one accident per million departures, making passenger air transportation the safest way to travel in the world [9]. Even so, accident rates continue to fall year after year, largely thanks to the work of aeronautical certification agencies.

2 OUTER SPACE EXPLORATION

The beginning of space exploration was marked by the race between the USA and USSR during the period historically known as the Cold War (1947-1991) [10]. The success of each technological achievement was widely celebrated and used by marketing on both sides, which tried to impose their ideology and influence on the polarized post-war world. The news of the launch and entry into orbit of the first satellite in history by the Russians, Sputnik (1957), brought fear and concern to the USA [10]. At the time, it was unclear what kind of information a satellite could provide to its creators.

This became known as the first era of human endeavors in outer space, when only a few governments or their agencies were involved in the various functions of launching space objects, operating and controlling them [11].

But what separates air space from outer space? This delineation has never been legally established, primarily due to the absence of activities conducted within the altitude range of airborne aircraft and the lowest orbiting spacecraft [12]. Although many experts consider this boundary to occur at 100 km altitude, the lowest satellite orbits are around 80 to 90 km. In addition, the initial definition of the Karman Line is located within the altitude range of 70 to 90 km rather than at 100 km [13].
After the world witnessed the importance of airspace sovereignty in the 50s, the use of outer space became a matter of national security. Consequently, in their early years, space exploration projects belonged to state programs with substantial government subsidies [14].

The space race continued quite fiercely until a human-crewed mission landed on the Moon [10]. Most historians agree as being the finish line of this technological marathon. In other words, the Soviet Union led for a long time, being responsible for sending the first man and woman into space, but it did not win the race. Much is speculated about the reasons that led the USSR to reduce priority in its lunar exploration program. The most accepted thesis is that the arrival of astronauts Neil Armstrong and Buzz Aldrin on the Moon, the death of Sergei Korolev (the principal Russian space engineer [10]), and the increase of nuclear tensions between the two powers that led the Kremlin to focus its resources on developing atomic warheads. [14].

This tension culminated in the first step towards the peaceful use of outer space: the Treaty on the Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other celestial bodies [10]. This treaty became known by the shortened name of the Outer Space Treaty (OST). The development of intercontinental ballistic missiles, in conjunction with the launch of Sputnik by the Soviet Union, hastened efforts to ban outer space for war purposes. In a rare case of unanimity, the UN passed, in October 1963, a resolution that prohibited the use of weapons of mass destruction in space [10]. After deliberating various proposals for an arms control treaty in outer space, the United Nations managed to draft the text of the OST signed by the United States, the United Kingdom, and the Soviet Union in 1967 [10].

The OST is the most fundamental of all the legal instruments of space legislation. Its principles promote the civil and peaceful use of space and celestial bodies, but its regulation only focuses on specific activities, especially on issues that could lead to international disputes. However, the treaty does not mention (or treats with ambiguity) several issues not considered at the time but which are becoming increasingly close, such as asteroid mining. The treaty declares that anyone can use outer space, but no one owns it and that its exploitation must be for the benefit of all peoples (whatever that means). It
also prohibits using nuclear weapons in space but does not go into detail on several sensitive issues, leaving them free for interpretation.

Despite its low relevance in the global geopolitical context, it is worth mentioning the Agreement that regulates the activities of States on the Moon and other celestial bodies, better known as the Moon Agreement, also negotiated at the UN and signed by 18 countries in 1979 [10]. The initiative brought a very timid advance to space legislation since nations capable of launching missions into space did not adhere to it. It brings in its text inspiring ideas, such as “the moon and its natural resources are a common heritage of humanity”. But it does not clarify how this perspective can coexist with the efforts of private companies in extracting and using those resources.

Starting in the 1980s, private organizations began to offer launch services and even operate space objects independently. States needed to assume jurisdiction over such organizations to comply with the international agreements related to the topic. This is considered the second era of human endeavors in outer space [11].

More recently, in the 21st century, a new space race began, with new private players and the expectation of commercial use of space resources. But there is still a vivid Russian presence among top space explorers and a robust Chinese rise in that arena. This is the newest and most complex context for human adventures in outer space.

3 THE NEW SPACE RACE

NASA’s recent move towards the Moon, the Artemis program [15], has as its main advertisement the first woman’s voyage to our natural satellite. But this program has much more important objectives in the geopolitical context, in confrontation with the current Chinese space program.

China intends to take its taikonauts to the moon. In a recent interview, NASA leader Bill Nelson stated, “We must be very concerned that China is landing on the Moon and saying: ‘It’s ours now, and you stay out’” [16]. Therefore, it seems that NASA’s presence on the Moon is essential if the US still wants to remain at the forefront of space exploration.
The Chinese plans are ambitious, and some significant results are already being demonstrated. In addition to announcing the discovery of liquid water on the lunar surface in 2020 [17], the Chinese space agency CNSA declared that it had found a new mineral on the Moon called Changesite-(Y) [18].

This clash is very similar to the first space race, disputed by the USA and USSR in the middle of the cold war. Because of this similarity, most people might be led to believe that the safety problem in space operations belongs to space agencies and their crews. Great mistake.

On May 2020, the main stage of the rocket Long March 5B, after separating from its main ship, re-entered the Earth’s atmosphere uncontrollably [19]. Weighing nearly 20 tons, it was the largest piece of space junk to fall to Earth’s soil in over 30 years. Its trajectory of debris formed a trail of nearly 2,200 km. Fortunately, none of its pieces did no harm to the physical integrity of any human beings, but they reached at least one village in Coˆte d’Ivoire. However, between 30 and 15 minutes before impact, this huge rocket stage soared over the vertical of highly populated areas such as Hollywood, Colorado Springs, and Central Park in New York.

On May 9th, 2021, several communication channels reported with some advance notice about the 20-ton piece of a Chinese rocket that could fall anywhere on a vast part of the globe. Figure 3 shows the area subjected to receiving the impacts of another Long March 5B re-entry, somewhere within 41.5 degrees of the equator. This covers almost the entire globe, and it was impossible to predict where it could land [20]. In fact, the rocket’s wreckage fell, luckily, into the Indian Ocean.
Once again, on July 30th, 2022, another heavy uncontrolled rocket stage of a Long March 5B crashed again over the Indian Ocean, this time just off the coast of Palawan Island, which is part of the Philippines [21]. It seems the Chinese Space Agency is heavily relying on luck.

In addition to the misadventures of state programs, the new space race relies on the ambitious plans of private companies. SpaceX, Blue Origin, and Virgin Galactic are the leading exponents of this vein of the space marathon. But, in fact, the international market already has hundreds of companies working to commercialize the use of outer space.

Starlink, the company that supplies internet signal via satellite owned by the tycoon Elon Musk, has already placed about 3,000 satellites in orbit. The regulatory body known as the Federal Communications Commission (FCC) of the United States has authorized SpaceX to proceed with the deployment of a constellation of 12,000 Starlink satellites. Additionally, the company has submitted documentation to an international regulatory authority to obtain clearance for an ambitious plan to launch up to 30,000 further spacecraft [22]. The direct supply of retail telecommunications services to the final consumer via satellites will render land-based equipment, like base stations, DSLAMs (Digital Subscriber Line Access Multiplexer), switches, antennas, and fiber,
obsolete [23]. Starlink already has some competitors. Amazon has announced the launch of its satellites via Blue Origin rockets, and two European companies (Eutelsat and OneWeb) have recently announced a merger. This market will be pretty heated, to the dismay of professional and amateur astronomers, as these objects reflect sunlight like small mirrors. In addition, they operate at frequencies that interfere with observations of cosmic events studied using radio telescopes.

In the field of manned flights, Blue Origin has already transported 31 passengers for space tourism [24]. Virgin Galactic has sold more than 100 tickets on similar flights. This is the third era [11]. And there are plans for a Chinese spacecraft that will offer suborbital tourism by 2025 [25]. In addition to these initiatives for the next decade, there are plans to use suborbital vehicles for passenger transportation flights [26].

At the top of the audacious goals of some private companies are lunar exploration, colonization of Mars, despite the romanticism that some companies face the challenge [27], and space mining, whose plans include taking advantage of near-Earth objects’ orbits (NEOs) that, at times, are very close to our planet [28] [29]. NASA and SpaceX have a project to launch a probe toward the asteroid 16 Psyche, which is part of the asteroid belt positioned between Mars and Jupiter. 16 Psyche is made of metals such as iron, nickel and gold, and its value could be worth more than USD 10 trillion [30].

4 CERTIFICATION OF SPACE PRODUCTS

UNOOSA - United Nations Office for Outer Space Affairs, founded in 1958, works to promote international cooperation in the peaceful use and exploration of space and the use of space science and technology for the development of a sustainable economy and society [31]. The office assists United Nations Member States in establishing legal and regulatory frameworks to govern space activities, as well as strengthening the capacity of developing countries to use space science technology and applications, helping to integrate space capabilities into their respective countries national programs.
With 95 member countries, including Brazil, COPUOS - Committee on the Peaceful Uses of Outer Space, created in 1959, is the UNOOSA Committee responsible for reviewing and fostering international cooperation in the peaceful uses of outer space, as well as considering legal issues arising from space exploration [32].

COPUOS has five main treaties within the scope of Space Law in the following chronological order [32]:

a) 1967: Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies;

b) 1968: Agreement on the Rescue of Astronauts, the Return of Astronauts, and the Return of Objects Launched into Outer Space;

c) 1972: Convention on International Liability for Damage Caused by Space Objects;

d) 1975: Convention on the Registration of Objects Launched into Outer Space; and

e) 1979: Agreement Governing the Activities of States on the Moon and Other Celestial Bodies.

In Brazil, the first step towards regulating space activities was taken by Law No 8,854 on February 10th, 1994 [33], which created the Brazilian Space Agency (AEB) to promote the development of space activities of national interest. In addition to the agency’s creation, the Law defines its powers, which we can highlight: “establish norms and issue licenses and authorizations related to space activities.”

The AEB can have its activities categorized into two large groups: fostering and regulation. Fostering activities support government launch operations (essentially FAB - Brazilian Air Force) and focus on safely accomplishing the mission. The recommended documents, which government operations must meet, are:

a) Air Force Command Directive DCA 800-2: Quality Assurance and Safety of Systems and Products at COMAER (Air Force Command) [34];

b) Instruction of the Air Force Command ICA 60-2: Procedure for Product Certification and Quality Management System in the Space Sector [35];
c) Instruction of the Air Force Command ICA 55-74: Planning and Execution of DCTA (Department of Aerospace Science and Technology) Operations [36]; and
d) Instruction of the Air Force Command ICA 55-90: Launching Rockets in the Scope of the DCTA [37].

AEB’s regulatory activities establish the rules for commercial launches in the national territory and focus on the safety of operations [38]. This security-mission dichotomy also occurs in Brazilian aviation, where the IFI, Instituto de Fomento e Coordenação Industrial (Industrial Fostering and Coordination Institute), responsible for the certification of Brazilian military aircraft, focuses on safe mission accomplishment, while ANAC - Agência Nacional de Aviação Civil, the Brazilian National Civil Aviation Agency, is concerned exclusively with the safety of air operations.

SINDAE is the Brazilian National System for the Development of Space Activities, established through Decree No. 1953 of July 10th, 1996, to organize the activities of the Brazilian Space Program [39]. The AEB, subordinated to the Ministry of Science, Technology and Innovations (MCTI), is the central body of SINDAE and, consequently, is responsible for formulating proposals to update the National Policy for the Development of Space Activities (PNDAE) and the Program of National Space Activities (PNAE), as well as for coordinating and monitoring the execution of PNAE actions.

The PNDAE, established by Decree No. 1,332 of December 8th, 1994 [40], establishes objectives and guidelines for national programs and projects related to the space area and has the PNAE as its main instrument for planning and ten-year programming. It is the main instrument used by Brazil to guarantee its autonomy in the space sector, with the mission of standing up to other countries that have already reached this level of technological mastery, such as the USA, Russia, China, France, Japan, and India.

The PNAE, as described above, is the instrument for planning Brazilian space activities for each ten years. Its last update took place through Ordinance AEB No. 756 on December 29th, 2021 [41]. Its impacts affect the sectors of communication, logistics, urban mobility, civil defense, mining, environment, health, education, and science,
among others, aiming to meet Brazilian society’s real needs. Examples of these needs include precision farming, consolidating intelligent cities, and harnessing renewable energy.

The Brazilian Air Force (FAB) also needed to establish its own strategic planning within the space sector. PESE, the Strategic Program for Space Systems, was born from this demand [42]. Its main objective is to provide space infrastructure to be used strategically and in a potentiating way in the Blue Amazon Management System (SisGAAz), in the Integrated Border Monitoring System (SISFRON), in the Brazilian Aerospace Defense System (SISDABRA), and in the Protection of the Amazon System (SIPAM) [42]. It is coordinated by the CCISE (Commission for the Coordination and Implementation of Space Systems), which aims to establish strategies in coordination with the PNAE. The FAB’s vision is that the PESE complements the PNAE by providing satellites with adequate capacity to support the Armed Forces missions and enable concrete improvements in the population’s lives [42].

The certification activity is strongly linked to quality assurance and aims to attest that certain requirements relating to a product, process, system, person, or organization are met. It is one of the three ways to carry out a conformity assessment [34]:

a) first-party conformity assessment - performed by the organization responsible for developing a product;

b) second-party conformity assessment - carried out by the client organization, i.e., responsible for the operation of the product (commonly conducted by verifying a sample of a lot); and

c) third-party conformity assessment - carried out by an organization exempt from the client-supplier relationship (usually certification, such as the National Institute of Standards and Technology – NIST, in the USA, for example).

In an Aeronautical Certification process, an organization impartial to the development and operation of the product or system aims to attest that a first-party conformity assessment, which in Brazil is known as Qualification, was well conducted, structured, and, most importantly, adequately documented.
Thanks to the unfolding efforts of the Chicago Convention and ICAO, there is now a vast base of airworthiness requirements. Each of these requirements has a very clear purpose: to ensure the safety of equipment, its crews, and, notably, the users of air transportation systems [6].

The space correlate term to airworthiness is not yet widely studied in academic circles: spaceworthiness [43]. This is not a lack of concern for the safety of space systems operators. Ultimately, getting an aircraft or its system through a certification process is expensive and time-consuming. Certification is estimated to cost around US$1 million for a primary category aircraft (three seats or less), US$25 million for a general aviation aircraft, and over US$100 million for a commercial aircraft [44]. Certification costs and delays consequences can run into millions of dollars, sometimes costing as much as developing the aircraft itself. When the company applying for a certification service exceeds the period of five years since the beginning of the process, the certification basis, i.e., the safety requirements that the design needs to meet, must be updated [45]. In such cases, design changes may be necessary. Depending on the delay, certification demands may derail the project.

But before labeling certification as a bureaucratic and costly process, it must be admitted that, in many situations, certification authorities encounter design problems that go unnoticed by manufacturers, allowing them to correct such issues before the project Entry Into Service (EIS). These corrections, at best, allow significant savings to the industry since changing a project in operation is much more costly than doing it during its development. In extreme situations, such design adjustments can be the determining factor to avoid an aeronautical accident that, in addition to tarnishing the manufacturer’s brand, imposes the inestimable loss of human lives.

Space systems developers must deal with a multitude of obstacles. To illustrate, space systems’ electronic components are about a thousand times more expensive on average than ordinary electronic components. The reason: space systems are bombarded with radiation of all kinds. The operational range of temperature that space products are susceptible to is colossal. On the planet’s surface, our systems are not subject to these
hostile environmental conditions, thanks to the protection provided by the Earth’s magnetic field and our atmosphere.

There are many arguments against requiring certification in the space sector in the same way as in the aeronautical industry. Space products are generally not serialized, as are aircraft and their parts. Most of the time, space products are used on a single occasion, as it is usually the case with space launch vehicles. This argument is valid to defend the exemption of production certification, which verifies the conformity of a product with the approved design. Still, it is not supported against the design certification, which verifies the compliance of a design with its requirements. Nevertheless, many good practices and procedures have already been standardized in Europe through ECSS - European Cooperation for Space Standardization [46].

ECSS is a collaboration between the European Space Agency (ESA), the European space industry (represented by Eurospace) and various space agencies, aiming to develop and maintain a single and coherent set of easy-to-apply standards for use in all European space activities. Such documents contain a set of procedural and documentary requirements necessary for the qualification processes of space systems in the European context. Its main objectives are to improve project cost efficiency, guarantee product quality and safety, expand interoperability, and harmonize the European space sector [46].

In Brazil, INPE, the National Institute for Space Research, responsible for the development and/or integration of dozens of satellites, has been using ECSS standards for some time. In addition, IFI, also responsible for authorizing space launches from Brazilian territory, adopts part of the ECSS standards in the investigation of the safety of launch operations.

Ordinance AEB nº 3 of January 7th, 2011 [47], established IFI as a Space Certification Body authorized to act within the scope of SINDAE in Brazil. This regulatory act appeared to place Brazil at the forefront of space certification activity. However, there was no systematic practice of certification among organizations that develop space systems in Brazil. INPE, as the main (and for a long time the only one) satellite design authority in Brazil, has never applied at IFI for a certification process for
any of its products. This spark of hope in favor of safer space products that adhere to its requirements was erased with the repeal of the 2011 ordinance through the publication of another regulation, n° 698, on August 31st, 2021 [48].

On the global stage, there is no consensus regarding the division between airspace and outer space, fostering a huge controversy in the application of aeronautical and space regulations. The world’s leading space agencies often argue about the safety of space operations. However, such debates occur particularly in the context of suborbital flights, given the large interface to the necessarily shared use of airspace with space activities, e.g., launch and re-entry [49] operations.

There is a latent need for international cooperation in the operation of current space systems, approaching the level currently used in the aeronautical sector. Space systems often require ground stations across different nations’ territories. Launching of private space vehicles from launch centers in foreign countries is already common. The Alcântara Launch Center in Brazil will host a series of twenty launches of the HANBIT-TLV rocket designed by the South Korean startup Innospace [50].

Several countries active in the space sector are considering or are developing new space legislation at different levels of maturity. Some already discuss a national policy for commercial (including manned) suborbital vehicle launches, orbital vehicle launches, and the operation of launch centers [49].

Unlike the USA, where the FAA (Federal Aviation Administration), responsible for regulating and certifying American aeronautical systems, is also responsible for regulating and controlling space launches, the European aeronautical agency EASA (European Union Aviation Safety Agency) is not yet active in the space segment. The roles of the current European aeronautical (EASA) and space (ESA) agencies are under discussion.

The FAA’s current approach to integrating air and space operations seeks a compromise between the two types of operation. Segregated use of airspace around the launch centers is made. The objective is to protect aircraft against potential hazards posed by the launch and re-entry of space vehicles. A relatively large volume of airspace around
these centers is considered, as a precautionary measure, in order to protect air traffic from hazards posed by failures in the operation of space systems, including falling debris.

The FAA is also already working on licensing for launch and reentry centers, as well as launch and reentry operations inside and outside the US [49]. However, the FAA does not exercise any control over operations conducted by the government, i.e., NASA and the Department of Defense. In addition, US laws on the subject limit the FAA’s authority in space matters. The FAA does not have a federal mandate to certify launch vehicles, restricted to licensing their operations. The success of private space missions is the sole responsibility of their respective operators.

The following stretch was included in the CSLAA - Commercial Space Launch Amendments Act of 2004: “... the regulatory standards governing human space flight must evolve as the industry matures so that regulations neither stifle technology development nor expose crew or space flight participants to avoidable risks as the public comes to expect greater safety for crew and space flight participants from the industry” [51]. There is a pondering of a compromise between burdening a poignant growing industry with overregulation and exposing the crew and passengers of private space missions to avoidable risks. This compromise also guides commercial aviation. What is the safest plane in the world? - The one that never takes off! Therefore, industry and governments invest a massive budget in defining tolerable limits for passengers’ exposure to risk. Engineering studies and techniques arise and are improved in favor of the development and safety of increasingly complex and highly integrated systems.

Due to the limitations of the FAA’s role, this agency has no responsibility for people aboard space vehicles. The scenario is only expected to change from September 30th, 2023, when the US Congress extended the “learning period” of its space industry. In this period, no new regulations related to the safety of human lives in space missions are expected [49].

The future approach to the combined use of airspace by aircraft and space vehicles contemplates an integrative vision. In addition to the expected growth of air traffic, especially when considering the insertion of new air vectors such as eVTOLS, service drones, etc., there is an expectation of shared and integrated use of airspace with space
vehicles. The launch and re-entry of space vehicles must take place in shared airspace with aircraft. The air traffic management systems should focus on preventing collisions between space vehicles and aircraft. The automation and precision of embedded systems should facilitate this transition.

It is likely that after the moratorium period (until September 30th, 2023), the FAA will also regulate and license space mission occupants, thus substantiating their security. The expectation is that only after commercial space travel becomes a routine FAA will begin to exercise the role of complete space authority: engaged in the regulation, certification, and inspection of production, spaceworthiness, operating companies, pilots, instruction, maintenance, Space Vehicle Dispatch, and Supply Chain [49].

Table 1 summarizes the main international agreements regarding space activities and national space operations regulations considered in this study.

Table 1 - International agreements and national regulations on space operations.

<table>
<thead>
<tr>
<th>Country/Region</th>
<th>Organization</th>
<th>Documents</th>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>UN</td>
<td>Rescue Agreement</td>
<td>1968</td>
<td>Agreement on the Rescue of Astronauts, the Return of Astronauts, and the Return of Objects Launched into Outer Space. The Rescue Agreement mandates that if a state party is aware that the crew of a spacecraft is in distress, it must inform both the launching authority and the Secretary General of the United Nations. The agreement requires that the state party must make every effort to rescue the personnel of the spacecraft who have landed within their territory due to accident, distress, emergency, or unintended landing. If the incident occurs in an area that is beyond the jurisdiction of any state, then any state party that is capable must provide assistance for the search and rescue operations, if necessary.</td>
</tr>
<tr>
<td>Global</td>
<td>UN</td>
<td>Liability Convention</td>
<td>1972</td>
<td>Convention on International Liability for Damage Caused by Space Objects. The principle of international responsibility dictates that any state within whose territory or facility a space object is launched assumes complete liability for any resultant damages, independently of the identity of the actual launcher. The launching state will be held accountable for all space objects launched from its territory or facility. If the launch is facilitated.</td>
</tr>
<tr>
<td>Global</td>
<td>UN</td>
<td>Registrations Convention</td>
<td>1975</td>
<td>Convention on the Registration of Objects Launched into Outer Space. The convention requires states to provide the United Nations with details about the orbit of each space object. A registry of launches was already being maintained by the United Nations as a result of a General Assembly Resolution in 1962.</td>
</tr>
<tr>
<td>Global</td>
<td>UN</td>
<td>Moon Agreement</td>
<td>1979</td>
<td>Agreement Governing the Activities of States on the Moon and Other Celestial Bodies. Not adopted by main nations involved in the current space race.</td>
</tr>
<tr>
<td>EUA</td>
<td>FAA</td>
<td>CFR Title 14 Chapter III: Commercial Space Transportation, Federal Aviation Administration, Department of Transportation</td>
<td>2027</td>
<td>The procedures and requirements applicable to the authorization and supervision of commercial space transportation activities conducted in the United States or by U.S. citizen. Not applicable to NASA and American Department of Defense.</td>
</tr>
<tr>
<td>Brazil</td>
<td>DCTA</td>
<td>ICA 55-74: Planning and Execution of DCTA Operations</td>
<td>2027</td>
<td>The procedures, requirements, and schedules applicable for planning and execution aerospace operations in the DCTA scope.</td>
</tr>
<tr>
<td>EUA</td>
<td>EASA/EESA</td>
<td>N/A</td>
<td>N/A</td>
<td>There are Policies and National Space Laws for most European Union countries. Nevertheless, a European space operations regulation is under discussion yet.</td>
</tr>
</tbody>
</table>

Source: Authors

The FAA is one of the most prestigious airworthiness agencies in the world. Its practices and experience are considered a model for several initiatives in the international
aerospace field. Logically, its approach greatly influences the progress of the spaceworthiness topic among the other authorities on the subject.

But if before it was not reasonable to invest in the certification of a single serial satellite, or any other space product, this is no longer the current reality, as discussed in this text. It makes perfect sense to establish a robust requirements verification process against a fleet of thousands of satellites, especially as these equipment will share the same operating environment as manned space vehicles, with increasing frequency. By the end of 2022, SpaceX has already reached the number of 192 launches of its Falcon 9 reusable stage rocket, with 150 successful landings and 129 flights of recovered stages (reflights) [52].

In addition to the already explored notion of spaceworthiness [43], considered an extension of the understanding of airworthiness to the space environment, the reuse of space vehicles will also require us to seek good practices already consolidated in the continuous use of aeronautical systems. Continued airworthiness instructions are approved by aeronautical authorities, and something similar should happen with space products. Various (mission) safety procedures can and should be corrected through software updates or commands. With the establishment of bases and fixed space routes, this demand will grow more and more.

One of the most relevant aspects of an aeronautical certification process is how the design organization will be able to maintain the airworthiness from its Entry into Service (EIS) until discarded. To this purpose, a set of requirements relating to the Instructions for Continued Airworthiness (ICA) must be complied with. These requirements are developed during certification activities and prepared in accordance with the applicable type certification basis and designed specification [45]. Its purpose is to ensure that the type certification airworthiness standard is maintained throughout the operational life of that system. ICAs are the basis for operator-approved maintenance data and allow for a schedule of inspection, adjustment, lubrication, removal, or replacement of parts and appliances. They are considered to be the means to keep a product airworthy.

Although European legislation on the subject is very scarce, it is possible to take the FAA Order 8110.4C [18] as a reference document and adapt from it the information...
necessary to implement a similar method in the space sector, promoting a process of continued spaceworthiness suitable for space products.

It is, therefore, urgent to create an international body with the same strength and technical rigor as the ICAO operating in the space sector. Standardizing and harmonizing safety requirements for space products will not only provide a better interface for the various players in the new space race. It will also allow the safe enjoyment of space systems by passengers, greater adherence to the mission and environmental protection requirements, including issues related to noise levels near launch centers, and systemic protections for human lives involved in space missions.

5 BRAZIL’S ROLE IN THE NEW CHALLENGES

Brazil is one of the founding members of the ICAO and has been participating in Group I of its Council, reserved for the most important countries in international air transportation, since its creation. The country actively participates in different committees, panels, and advisory groups of the ICAO and is currently part of the ICAO Task Force for the Recovery of Aviation in the context of the COVID-19 pandemic [53]. The ICAO Secretariat has Brazilian nationals participating, including in a management capacity. The Brazilian representative has been reelected to the Air Navigation Commission (ANC), the ICAO Council’s principal advisory body for aviation technical issues, the development and adoption of SARPs (Standards and Recommended Practices) and their inclusion in the annexes to the Chicago Convention. Since 2018, the Regional Director of the ICAO for South America, located in Lima-Peru, has been occupied by a Brazilian [53].

As one of the largest civil aviation markets in the world, Brazil exercises leadership in discussions within the ICAO, justified by the relevance of civil aviation to Brazil and of Brazil to international civil aviation, as well as the strong bond that ties Brazil to the history of aviation [53].

Brazil maintains a Permanent Delegation to the ICAO Council, headed by a representative from the Ministry of Foreign Affairs and permanently advised by the Air
Force Command, the National Civil Aviation Agency, and the Federal Police Department [53].

Considering: (a) the relevance of the subject and the international need for standardization and harmonization of regulations in the development and operation of space systems; (b) the history, experience, and airworthiness maturity of Brazilian aviation authorities in conducting hundreds of aeronautical certification processes and licenses for operation; (c) Brazil’s growing and promising participation in the space launch market; and (d) Brazil’s conduct in leading the Air Navigation Commission of ICAO; these factors make Brazil one of the most independent and geopolitically unbiased leaders to moderate the necessary agreements for the creation of an organization like ICAO for space matters.

6 CONCLUSION

This article sought to draw a parallel between the histories of the aeronautical and space industries and highlight the similarities and distinctions between these sectors. The high degree of applicability of lessons learned from commercial aviation in the use of space systems is noticeable.

There is a very famous saying among airworthiness experts that, while very shocking, is endowed with a powerful message: “The safety requirements of air operations were written with blood.” Most of the requirements imposed by the aeronautical authorities on manufacturers, operators, maintainers, and trainers have an unfortunate origin. Still, they all aim to prevent an accident from happening again for the exact causes.

The path we will take, the risks we will take, and the losses we will have to accept will all depend on our ability to cooperate and set aside our differences and ambitions for the safe and fair use of outer space. The delay in establishing laws with a global reach could lead us to certain irreversible situations, such as the massive number of satellites already in orbit and many more that are yet to come and will undoubtedly change Earth’s face forever. Will we wait for a heavy rocket stage to crash in a densely populated region
to finally demand more effective control of space product launchers over their systems? The answers to this and other inconvenient questions will dictate how much we are willing to expose the safety of passengers, crew, and others involved in space operations for the sake of the intrepid space products industry to flourish. We depend on it to continue to explore humanity’s ultimate frontier safely.

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