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Bibliometric study of research in aeronautics, cyberspace, and space exploration for the Colombian Aerospace Force

Estudio bibliométrico de las investigaciones en aeronáutica, ciberespacio y exploración espacial para la Fuerza Aeroespacial Colombiana

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ABSTRACT. This bibliometric study addresses the dynamics of publication in three thematic areas relevant to the development of the aerospace sector of the Colombian Aerospace Force, such as aeronautics, space, and cyberspace. The aim is to identify the thematic trends and research emphases published in 2000-2023 and made visible in the Scopus database. The information was analyzed globally and for short intervals with tools such as VoSviewer, identifying thematic clusters based on the co-occurrence of terms and trends of emphasis in different topics. A transition towards multidisciplinary and technologically advanced approaches in aeronautics, cyberspace, and space exploration was evidenced, highlighting their impact on improving research and development practices and strategies within these critical fields.

KEYWORDS: Aerospace; bibliometrics; cyberspace; research; space; technology.

RESUMEN. Este estudio bibliométrico aborda la dinámica de publicación en tres áreas temáticas relevantes para el desarrollo del sector aeroespacial de la Fuerza Aeroespacial Colombiana, como son la aeronáutica, el espacio y el ciberespacio. Se busca identificar las tendencias temáticas y énfasis de investigación publicados en el periodo 2000-2023 visibilizadas en la base de datos Scopus. La información se analizó de forma global y por intervalos cortos con herramientas como VoSviewer, identificando clústeres temáticos con base en la coocurrencia de términos y tendencias de énfasis en diferentes tópicos. Se evidenció una transición hacia enfoques multidisciplinarios y tecnológicamente avanzados en aeronáutica, ciberespacio y exploración espacial, resaltando su impacto en el mejoramiento de las prácticas y estrategias de investigación y desarrollo dentro de estos campos críticos.

PALABRAS CLAVE: Aero espacio; bibliometría; ciberespacio; espacio; investigación; tecnología.

Section: DOSSIER • Scientific and technological research article

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Introduction

There is a need to strengthen the aerospace economy and industry in Colombia, a sector recognized for its short-term growth potential and key to the reindustrialization of the country, as stated in the National Development Plan 2023-2026 (Lemos & Conde Rubiano, 2023). To current public policies, it is necessary to promote the development of the aerospace industry and technological sovereignty by strengthening and developing scientific and technological research activities in this sector (Castrillón Riascos & Suárez Amador, 2024).

Considering this initiative, the Colombian Aerospace Force - FAC-, as an entity at the forefront within its strategic plan for Air and Space development (EDAES 2042), seeks to address these activities through three components: 1) aeronautical, 2) space and 3) cyberspace, which correspond with its missional activities involving the domain of air, space and cyberspace; these components are interdependent and their fields of study converge in several sectors, both academic and productive, as well as economic (Urbina Carrero, 2017; Fuerza Aérea Colombiana, 2020; Chávez & Velásquez, 2017). In Colombia, the aeronautical component is the one that has been mainly addressed, and according to the report presented by the Civil Aeronautics of Colombia (Aeronáutica Civil, 2020), air transportation contributes 2.7% to the country's GDP, including the generation of production and value chains derived from it. Likewise, this sector generates around 600,000 jobs, 76,000 of which are directly related to the supply chains necessary for its operation.

In this sense, the FAC articulates these components from its Science, Technology, and Innovation System, formed by four research centers, organized as follows: aeronautical program - Aeronautical Innovation Technology Center (CETIA); space program - Center for Research in Aerospace Technologies (CITAE) and Center for Aerospace Research in Science (CIAEC); and cyberspace program - Aerospace Technology Center for Defense (CETAD). Likewise, its lines of research are articulated with these components, for which continuous technological surveillance is required, seeking to identify and address the frontier issues in each sector, allowing a significant technological development in the aerospace sector, contributing to the acquisition of national capabilities that favor technological independence and institutional autonomy.

From a bibliographic search and consultation, fields of study in the aeronautical area are identified, highlighting topics such as composite materials, aerospace engineering, control systems, and artificial intelligence. A field that is under exploration is related to environmental sciences, oriented to the design of new electric or hybrid propulsion systems, finding within this research around unmanned aircraft (Khan et al., 2019), and the use of materials to increase fuel efficiency or to improve fatigue resistance (Aguado-Montero et al., 2022).

A similar review in the field of space allowed identifying studies related to the development of technologies for planetary exploration missions (Rincon et al., 2021), research on nanosatellites or microsatellites (Inamori et al., 2016), the extraction of mineral resources and water from asteroids, and the development of new technologies (Hessel et al., 2021).

From cyberspace, the literature provides evidence of predominant fields of study such as privacy on the Internet, computer security, artificial intelligence, political science, and social issues. Studies were also found on robust security systems for protecting aircraft and satellites against cyber-attacks (Rahman et al., 2023), the development of secure communications technologies, quantum communication networks (Miranda et al., 2021), artificial intelligence and machine learning (Geluvaraj et al., 2019).

Considering the established relevance for the country of these three fields of development of the aerospace industry, it is considered highly relevant to know how research in these fields has been evolving in the last decade. For this purpose, a bibliometric analysis was carried out based on the publications visible in Scopus during the period 2000 - 2023, focused on the aeronautical, space, and cyberspace fields.

The purpose of this research is to explore both the scope and interests in research and development in these three areas at a global level through a rigorous examination of the available academic and technical literature, identifying priority areas of research, emerging trends, and the influence of such research on the evolution of aerospace capabilities.

This analysis offers a panoramic view of this field's scientific and technical production. It provides a deeper understanding of how research and development can shape the future of the FAC. By highlighting focus areas and strategic needs, it is intended to guide future research and development efforts to strengthen further the FAC's contribution to Colombia's security and progress.

This article begins with a theoretical framework that contextualizes the importance of the research conducted and provides the reader with an overview of aerospace development for the FAC and the country. At the same time, it analyzes the country's capacities and prospects in this industry field. Secondly, the research method used to conduct the bibliometric analysis is established, and the results are presented.

The results are organized according to the development field and are presented by periods (2010-2013; 2014-2016; 2017-2019; 2020-2023). Additionally, an analysis using a documentary coupling network is presented, which allows for establishing clusters that evidence different thematic approaches to research in the analyzed areas. Finally, conclusions and discussions derived from the bibliometric analysis are presented, which is expected to provide a global overview of research in the fields of aeronautics, space, and cyberspace, which can serve as a baseline to guide the development of the Colombian aerospace industry, and the decision making of both governmental and private organizations.

Research Foundations and Context

In this work, a literature review has been carried out to clarify the conceptual scope of the terms addressed: aeronautics, space, and cyberspace. Thus, aeronautics is the fundamental scientific discipline focused on designing, manufacturing, and operating aircraft, including manned and unmanned variants (Voracek, 2020). Critical areas of study, such as aerody-

namics, aeronautical structures, propulsion systems, and control mechanisms, stand out in this field. The goals of aeronautics research, as identified in the papers of Vivian and Marsh (1921), include the improvement of flight efficiency, safety, and sustainability. Additionally, this discipline seeks to develop innovative technologies to address contemporary challenges, such as air traffic congestion and emissions reduction.

Space exploration and utilization encompasses a wide range of activities, from the complex process of designing and strategically launching satellites to ambitious interplanetary missions and the search for extraterrestrial ventures (El-Sheimy & Youssef, 2020). At the core of these activities are advanced disciplines such as rocket engineering, which involves the development of sophisticated propulsion systems and navigation systems that are crucial for precise maneuvering in the vastness of space (De Mol, 2023). In addition, remote sensing and astrobiology play a fundamental role: the former provides essential data for Earth observation and environmental monitoring. At the same time, the latter allows a better understanding of the possibility of life on other planets. Space research enhances the understanding of the universe, fostering substantial technological advances and enabling innovations in the drive for space exploration and improving various terrestrial applications, such as global communications, detailed Earth observation, and exploration of space resources (Saeed et al., 2021).

Recent studies still show how space exploration opens new frontiers for humanity and is a crucial source of technological innovation, propelling advances that transcend the space domain to benefit society (Varadharajan & Suri, 2024). Research in this area of knowledge offers profound implications for both theoretical knowledge and practical applications, pushing the technological frontier and opening up new possibilities for economic and scientific development.

Based on space exploration and its technological advances, integrating cybersecurity measures is a fundamental component of protecting these innovations. This transition emphasizes the critical importance of cyber technologies in the modern aerospace sector.

The cyberspace domain in aerospace primarily focuses on robust security and meticulous management of the computer systems that support aeronautical and space activities. This includes developing sophisticated satellite control software, comprehensive cyber-attack protection strategies, and effective management of space-derived data (Antonopoulos, 2021). Within this context, cybersecurity may emerge as a fundamental discipline designed to safeguard operational integrity and protect sensitive information from potential breaches that jeopardize national and global security. In addition, the application of artificial intelligence to data management seeks to optimize the processing and analysis of large amounts of spatial data, improving decision-making processes and operational efficiency (Kavak et al., 2021). Other authors emphasize the importance of having secure communication networks to maintain the confidentiality and reliability of transmissions between ground stations and orbital assets (Srivastava et al., 2022). These critical elements of systems, research, and continued development in cybersecurity contribute to anticipating, mitigating, and managing risks associated with evolving cyber threats in the aerospace sector.

The literature review reveals that each of these areas plays an important role in developing and strengthening a country's aerospace industry. Collectively, these interdependent areas promote an ecosystem that not only drives technical and competitive progress but also promotes the strategic, economic, and scientific advancement of nations, highlighting the interconnectedness and multifaceted importance of the aerospace industry in today's global landscape (Leśnikowski, 2021; Nawrocki et al., 2021; Sloan et al., 2021; Varadharajan & Suri, 2024).

This global overview of aeronautics, space exploration, and cybersecurity highlights the importance of reviewing these elements within specific national contexts, such as Colombia, where the integration of these disciplines is crucial to strengthening the country's strategic capabilities.

The Colombian Aerospace Force (FAC) is a fundamental pillar in national defense and security, playing a decisive role in the military and strategic spheres (Urbina Carrero, 2017). Research and development emerge as central aspects to enhance the FAC's operational capacity, increase its efficiency, and ensure its leadership on the technological front (Kolstoe & Holden, 2020).

Under this consideration, the Colombian Aerospace Force recognizes through its Center for Technological Development Science, Technology and Innovation Directorate (CDT DICTI), the aeronautical, space, and cyberspace components as fundamental pillars that allow scientific and technological development in the fulfillment of its mission, as a strategy of technological independence, autonomy and acquisition of institutional capabilities. This Technological Development Center is the first recognized by the Ministry of Science, Technology, and Innovation for the Colombian Armed Forces. It has three branches nationwide, each of which addresses a particular component, as listed below:

- 1) Aeronautical Innovation Technological Center (CETIA): leads studies and research in the aeronautical logistics field through strategic Research and Development projects for the Colombian Aerospace Force that generate a military advantage to strengthen air dominance.
- 2) Center for Research in Aerospace Technologies (CITAE): This center leads the space research program, with emphasis on the development of satellite platforms and systems. It also develops projects oriented to launch rocketry systems, mission control software, and Artificial Intelligence applied to space missions and payloads.
- 3) Aerospace Technology Center for Defense (CETAD): stands out in the development of research, development, and innovation (R&D&I) projects for the Colombian Aerospace Force in the areas of command-and-control systems, drone detection, identification and neutralization systems, artificial intelligence and expert systems.

Based on the above, the following guiding question is posed for this study: What are the thematic areas on which global research and development in aeronautics, space, and

cyberspace have focused from 2000 to 2023, and how has their interrelationship evolved over this period?

Methods

In this work, mixed statistical techniques are used, applying a quantitative approach to obtain some bibliometric production indicators such as productivity per year and its growth in the analyzed period, the most productive author, the most published type of document, countries with the most significant contribution in each thematic field, among others. The analysis for short periods and the documentary coupling are approached from the qualitative point of view. Thus, the analysis and results section comprises three modules for each of these lines of work (aeronautics, cyberspace, space), aiming to provide a deep and nuanced understanding of the trends and patterns in the bibliographic corpus (Figure 1).

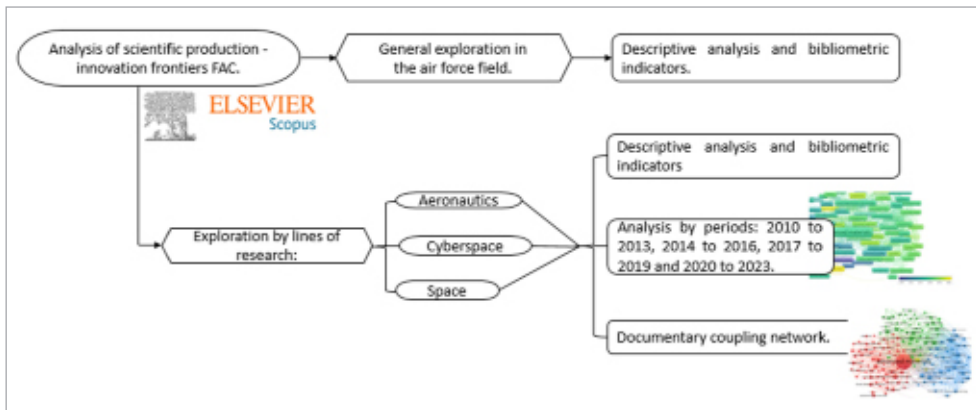


Figure 1. Methodological design implemented

Note. Source: own elaboration

In the first module, a fundamental descriptive bibliometric analysis is performed, complemented by production indicators, establishing the overall picture of published research between 2000 and 2023. This module serves as a basis for understanding the volume and geographic distribution of contributions to these fields, providing an initial view of the dynamism and growth of the body of knowledge.

Illustrated below is one of the search equations used to identify the overall publications in the force area field:

TITLE-ABS-KEY("Military Research" OR "Aerospace Force" OR "National Security" OR "Military Technology" OR "National Defense" OR "Aerospace Capabilities" OR "Defense Policy" OR "Military Technological Innovation" OR "Aerospace Operations" OR "Security and Defense" OR "Autonomous Aircraft" OR "Advanced materials" OR "Electric and hybrid propulsion" OR "Advanced aerodynamic design" OR "remotely piloted aerial vehicles" OR "Drone development" OR "Space Exploration" OR "Small satellites and constellations" OR

“Space mining” OR “Space debris” OR “development of nanosatellites” OR “nanocube sat” OR “Aerospace cybersecurity” OR “Secure communications” OR “Cyber resilience” OR “command and control systems” OR “radar technology” OR (“Artificial intelligence” OR “machine learning” AND “cyberspace”).

The second module goes deeper with a short period analysis, focusing specifically on the themes of publications over time. This approach allows the identification of emerging trends, shifts in focus, and the evolution of research interests within each area, highlighting how priorities and areas of interest have shifted over the last two decades.

Finally, a word co-occurrence analysis uses clusters, revealing the relationships and connections between key concepts within the corpus. This advanced analysis highlights central themes and interconnected research areas within aeronautics, cyberspace, and space exploration, offering valuable insights into the synergies and multidisciplinary approaches that characterize these areas of study.

These three modules form a comprehensive outline of the trajectory and contours of knowledge in these domains, reflecting the research’s depth and breadth and establishing a solid foundation for future inquiry and technological development.

Results

Within the general overview of the research conducted in the military field visible in the international Scopus database, the general search yielded 106,443 documents at the date of consultation on November 22, 2023, with a cleaning and purification process, 90,074 documents corresponding to the period 2000 - 2023 were finally processed (Figure 2).

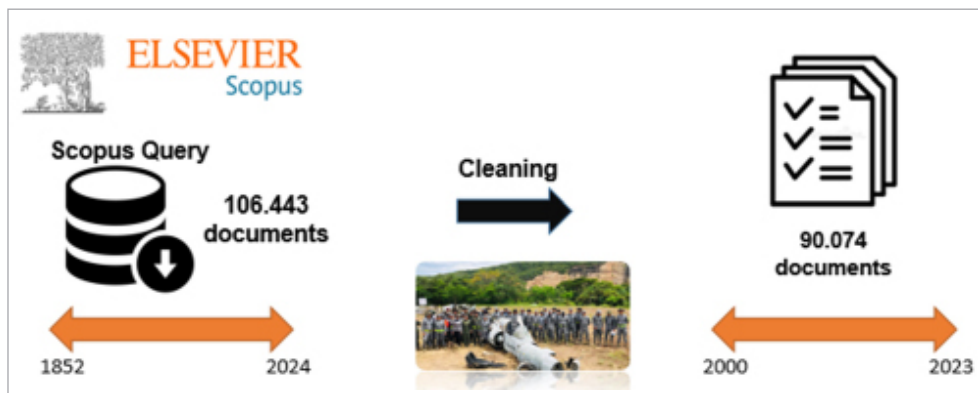


Figure 2. Consultation of visible military research in Scopus

Note. Source: own elaboration

An increasing number of publications in military research associated with some of the descriptor terms used were observed, with the United States and China being the countries with the most significant contribution to research in this field; 42% of the publications were

scientific articles, 38.6% were conference papers, and the remaining 19.4% were other types of publications. Among the 10 most productive authors in the field, Grevatt J, Klinkrad H, and Holdanowicz stand out with more than 100 papers each.

Likewise, queries were made for each thematic line of interest (aeronautics, cyber-space, space), the results of which are presented below:

Line of research: Aeronautics

A total of 16,331 documents were found, showing an increase in the number of publications since 2000, which is why the study period was established from 2000 to 2023, leaving a total of 13,116 documents; the descriptors used for the consultation can be seen in Figure 3.

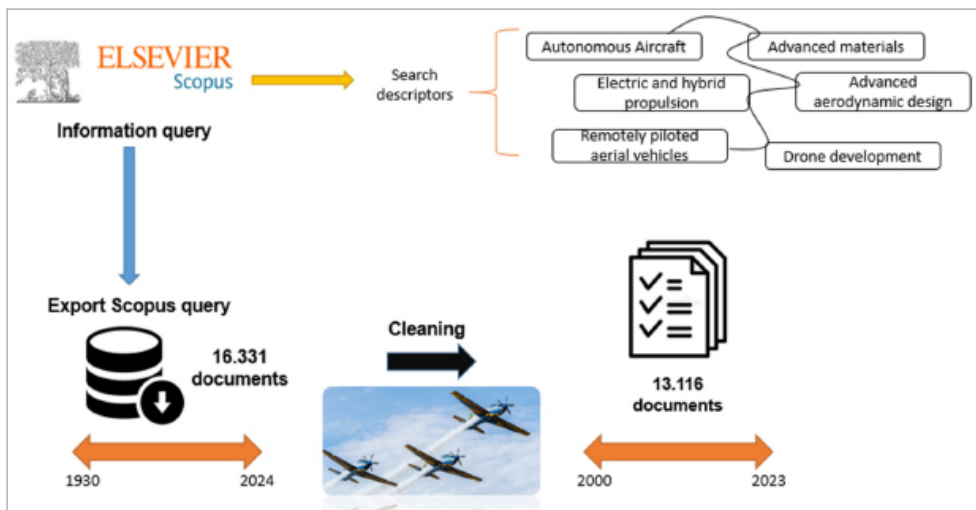


Figure 3. Consultation of research in the aeronautics line visible in Scopus
Note. Source: own elaboration

Descriptive analysis and bibliometric indicators

The United States and China have the highest contribution to research in this field; 43.8% of the publications were scientific articles, 24.6% ‘were conference papers’, and the remaining 31.6% were other types of publications. Among the top 10 most productive authors in the field, Tiwari A, Laurencin C.T, and Rogers J.A stand out with more than 25 papers each. “Advanced Materials” is the journal with the highest number of publications in the field, and it is also evident that, in the last years of the period studied, the number of papers published in this journal has increased.

Analysis of aeronautics research over time

Bibliometric analysis through VOSviewer made it possible to visualize the evolution and focus of research in the aeronautics field from 2010 to 2023. The tool uses font size to indicate

Documentary coupling network

Figure 5 identifies the co-occurrence of words in aeronautics publications, grouping them into three clusters differentiated by color, each representing a specific thematic set within the field.

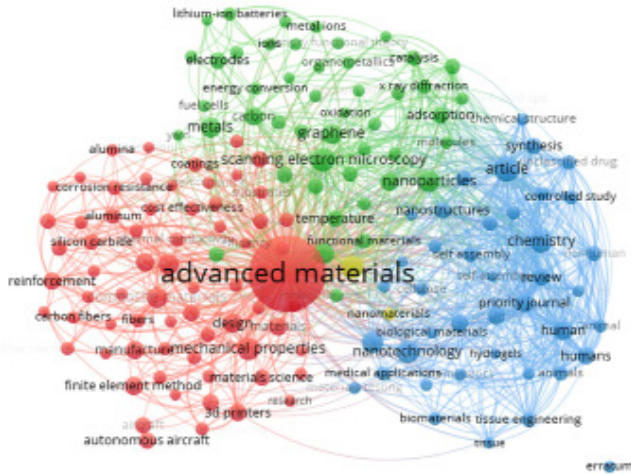


Figure 5. Co-occurrence network in the aeronautical field

Note. Source: own elaboration

Table 2. Analysis of the clusters identified in the aeronautical field

| Cluster | Description |
|---------|--|
| 1 | <p>Identified in blue: Chemistry and Nanotechnology in Aeronautics.</p> <p>This cluster includes terms such as chemistry, nanotechnology, controlled study, human synthesis, animals, hydrogels, biomaterials, and self-assembly. It suggests a focus on fundamental and applied research in chemistry and nanotechnology, highlighting the importance of biomaterials and hydrogels. The mention of controlled human and animal studies indicates an interest in biological and medical applications of these technologies, potentially relevant to health and safety in aeronautics.</p> |
| 2 | <p>Identified in red: Advanced Materials and Manufacturing in Aeronautics.</p> <p>This cluster encompasses advanced materials, reinforcement, corrosion, silicon, carbon, the finite element method, strength, alumina, materials design, 3D printers, autonomous aircraft, manufacturing, and fibers. It focuses on developing advanced materials and manufacturing technologies, including 3D printing and designing specific materials for applications in autonomous aircraft and reinforced structures.</p> |
| 3 | <p>Identified in green: Microscopy and Nanoparticles in Aeronautics.</p> <p>Finally, this cluster includes terms such as electron microscopy, graphene, carbon, nanoparticles, conversion, electrodes, microscopy, catalysis, lithium-ion batteries, metals, oxidation, temperature, organometallics, and diffraction. This group focuses on the characterization and application of nanoparticles and advanced materials such as graphene, especially in contexts such as catalysis and lithium-ion batteries, suggesting an interest in improving the energy and efficiency of aeronautical systems.</p> |

Note. Source: own elaboration

Line of research: Cyberspace

Analogous to the query made in the aeronautics line, cyberspace is explored, finding 16,331 documents and leaving us with a total of 13,116; Figure 6 shows the descriptors used for the query.

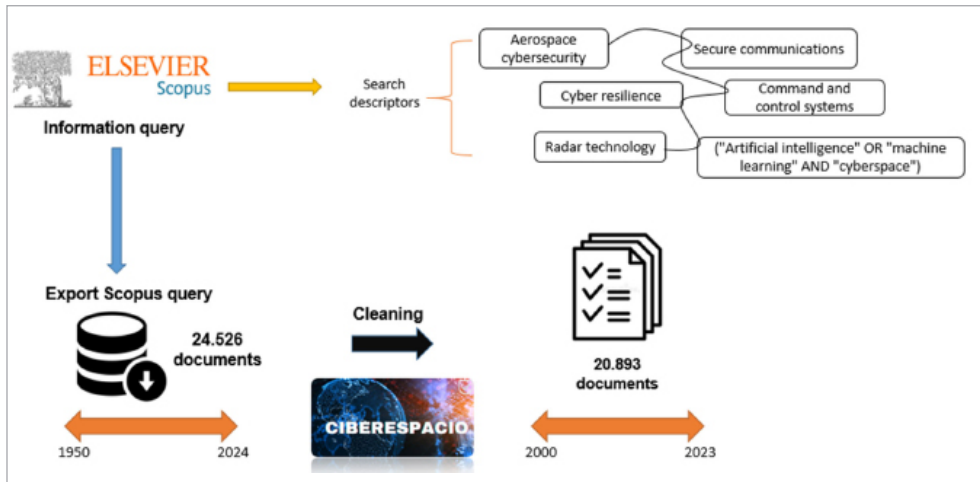


Figure 6. Consultation of research in the cyberspace line visible in Scopus

Note. Source: own elaboration

Descriptive analysis and bibliometric indicators

Noting an increasing number of publications in this thematic line, with China and the United States being the countries with the most significant contribution to research around this field; 50% of the publications were 'conference papers', 41% scientific articles, and the remaining 9% other types of publications. Among the 10 most productive authors in the field, Ding Q, Das A.K, and Poor H.V. stand out with more than 40 papers each. "IEEE Access" is the journal that stands out in the last years of the period studied. However, the number of papers published in it has decreased.

Analysis of Cyberspace research. Over time

Analogous to the previous section, this section presents the changes in research interest in cyberspace over the years. From Figure 7, it can be seen that the terms "command and control systems," "secure communications," and "cryptography" are highlighted by their larger size in the box, indicating a higher frequency of publication. Another set of terms, such as "chaotic systems," computer simulation, synchronization, and "internet of things," present a smaller size, suggesting a growing but more recent interest.

| Cluster | Description |
|---------|---|
| 4 | <p>Identified in purple: Artificial Intelligence and Cybersecurity.</p> <p>The purple cluster includes artificial intelligence, computer crime, cybersecurity, machine learning, machine learning, learning systems, botnet, and generation algorithms. This cluster emphasizes the use of artificial intelligence and machine learning to address challenges in cybersecurity, including the detection and neutralization of threats such as botnets.</p> |
| 5 | <p>Identified in yellow: Physical Layer Security and Networking.</p> <p>Finally, the yellow cluster presents terms such as network layers, physical layer security, interference, antennas, cognitive radio, outages, communication channels, secrecy capability, MIMO systems, and beamforming. This cluster highlights research in network and communication technologies, focusing on the robustness and security of physical communication infrastructures.</p> |

Note. Source: own elaboration

Line of research: Spatial

Figure 9 shows a summary of the consultation found when researching the publications in this thematic line:

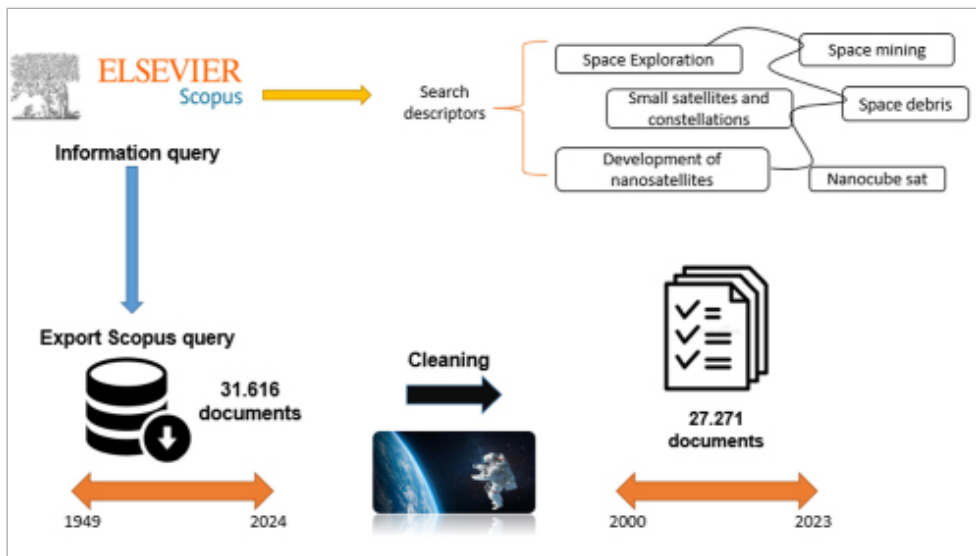


Figure 9. Consultation of research in the spatial line visible in Scopus

Note. Source: own elaboration

Descriptive analysis and bibliometric indicators

An increasing number of publications in this line was evidenced, with the United States and China being the countries with the most significant contribution to research in this field; 56.3% of the publications were conference papers, 34.3% were scientific articles, and the

| <i>Period</i> | <i>Description</i> |
|---------------|--|
| 2014 to 2016 | During this interval, terms such as “planet Earth,” field programmable gate arrays, “spaceflight,” “space junk,” cameras, “human spaceflight,” and “radiation protection” appear. This set indicates an expansion in topics of interest, encompassing space debris management, astronaut safety and health, and Earth observation. |
| 2017 to 2019 | The descriptors “deep space exploration,” “integrated circuit design,” “space tensors,” ecosystems, and “microgravity” highlight a focus on more ambitious and advanced challenges in space exploration, including life and systems in microgravity environments, as well as technology for missions beyond low-Earth orbit. |
| 2020 to 2023 | In the latter period, terms such as “object detection,” “machine learning,” “convolution,” and “functional neural networks” indicate a trend toward applying artificial intelligence and deep learning to spatial observation and analysis. Including these technologies suggests a move toward automation and improved spatial data collection and processing efficiency. |

Note. Source: own elaboration

Document coupling network

Figure 11 identifies five distinct thematic clusters in spatial studies based on word co-occurrence, with each color representing a specific group of interest.

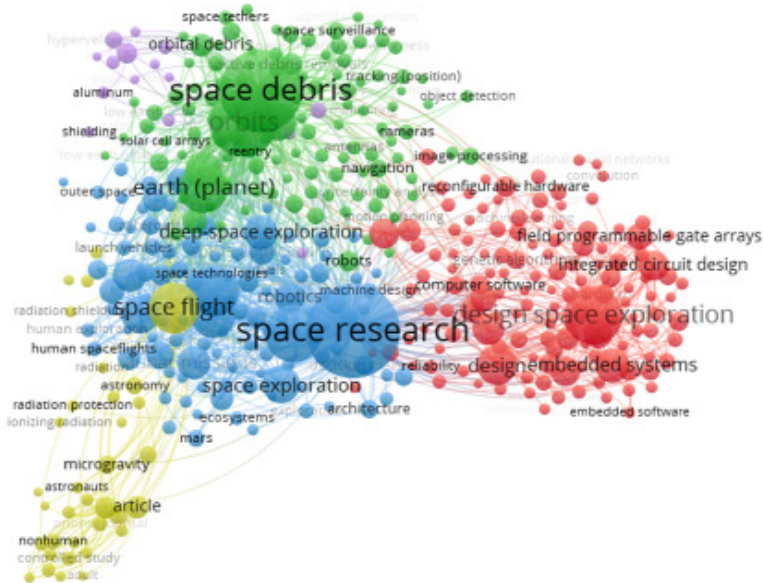


Figure 11. Coupling network on the spatial line

Note. Source: own elaboration

Table 6. Analysis of the clusters identified in the spatial field

| Cluster | Description |
|---------|--|
| 1 | Identified in blue: Space Research and Technology. The blue cluster combines terms such as space research, robotics, space technologies, space exploration, mission, Mars, ecosystems, and vehicles. This cluster highlights a focus on advanced research and development of technologies aimed at the exploration and study of celestial bodies, particularly Mars, emphasizing the importance of vehicles and robotics in these missions. |
| 2 | Identified in red: Space Systems Design and Engineering. The red cluster includes space design exploration, field programmable gate arrays, embedded system design, circuit design, reconfigurable hardware, computer software, and embedded software. This set of terms suggests a concentration on design and engineering solutions for space systems, emphasizing hardware and software flexibility and adaptability. |
| 3 | Identified in green: Space Debris and Surveillance. The green cluster comprises terms such as space debris, orbit, planet Earth, cameras, navigation, object detection, space surveillance, space tensors, active debris, and reentry. This cluster indicates an interest in space debris management and mitigation, as well as Earth orbit surveillance and safety. |
| 4 | Identified in purple: Protection and Materials in Space. The purple cluster groups terms such as orbital, aluminum, shielding, hypervelocity, and low Earth orbit. This cluster focuses on materials and technologies designed to protect spacecraft and satellites in space, particularly from micro-meteorite impact and space radiation. |
| 5 | Identified in yellow: Astronomy and Human Studies in Microgravity. Finally, the yellow cluster covers astronomy, microgravity, astronauts, articles, non-human, controlled study, ionizing radiation, and protection. This cluster focuses on astronomical research and the effects of microgravity and radiation on humans and other living organisms in space. |

Note. Source: own elaboration

Discussion

This research has outlined important studies in aeronautics, space, and cyberspace, highlighting trends and advances through publications from 2000 to 2023. These findings broaden the understanding of each field and their interconnection, contributing as a research benchmark for the strategic needs of the FAC and a global context.

By comparing these results with the studies conducted by Alves de Oliveira (2022), a convergence is observed in the identification of research on space exploration topics on new technologies and new materials; however, this study provides a broader spectrum of topics that are published in the Scopus database and proposes a new perspective of trend analysis by periods.

Additionally, even though topics of growing and recent integration, such as artificial intelligence (AI) in aerospace operations, are identified, as reported by Morgan et al. (2020), this study shows that the application of AI in the air force in developing countries such as

Colombia is still in an incipient phase of growth. These results are by Campos Chaparro et al. (2023).

In aeronautics, the evolution of topics reflects findings similar to those of Rincon et al. (2021), with the acquisition of data through radar technologies aiming to improve capabilities to obtain information on various celestial surfaces. Regarding space and cyberspace, the results suggest research on techniques for protecting information through encrypted algorithms that guarantee the confidentiality and integrity of data with the development of advanced cryptographic techniques. This area reflected less attention in previous studies by Geluvaraj et al. (2019).

One of the unexpected findings was the significant increase in cyberspace-related publications from 2017 to 2019, which could be attributed to the increase in cyberattacks globally and the need to strengthen cyber capabilities in military contexts. This result aligns with the growth trend in some areas of knowledge, which indicates an exponential trend (Jiménez González et al., 2018).

Conclusion

In aeronautics, each period shows a coherent evolution in research interests and technologies, reflecting a path toward greater sustainability, efficiency, and adaptability of the materials and technologies used. Thus, it is evident that period 1 marks a phase of intensive exploration and foundation in materials science, crucial for later advances in aeronautics. Period 2 shows an evolution towards more detailed research at the nano level and integrating different disciplines, suggesting an enrichment of the aeronautical field with new perspectives and materials. Period 3 emphasizes the application and functionality of new materials, with a notable focus on sustainability and bioengineering, and period 4 reflects a consolidation of advances in materials and technologies, with a clear focus on energy efficiency, sustainability, and innovation in manufacturing processes.

Of the documentary coupling networks in the aeronautics line, we can highlight the exploration of new materials and techniques at the interface of chemistry and nanotechnology, with potential applications in the improvement of aeronautical components and systems, as well as in safety and aerospace medicine (cluster 1). Likewise, innovation in materials and manufacturing processes is highlighted, aimed at improving aeronautical components' efficiency, strength, and functionality, with special attention to autonomous capabilities and customization through 3D printing (cluster 2). There is also a focus on deepening knowledge about nanoscale materials and their practical applications, aiming at process optimization and improving energy efficiency in aeronautical systems (cluster 3).

Each cluster reflects an area of interest and development within aeronautics, from exploring new materials and manufacturing processes to applying nanotechnology and energy optimization, demonstrating the richness and diversity of research in this field. In cyberspace,

for the first period, the focus is on control systems and military operations, underlining the priority of securing and optimizing communication and decision-making in critical environments. In period 2, the diversification of topics suggests an expansion of the field towards protection against emerging threats and incorporating advanced technologies to strengthen security. For period 3, an integrative approach to security is highlighted, considering technical and human aspects and adapting solutions to new needs and technologies. Finally, in period 4, the focus on disruptive technologies indicates preparation to face future challenges in cyberspace with innovative tools, marking an era of transformation in security and digital information management.

Each period reflects an evolution in focus and concerns within the vast field of cyberspace, from security in communications and military operations to the incorporation of artificial intelligence and blockchain for security and efficiency in an increasingly connected world. In the documentary *Coupling Networks in the Cyberspace Line*, emphasis is placed on developing and applying advanced cryptographic techniques and systems theories to secure communications in cyberspace, responding to the growing need for privacy and security (cluster 1). Similarly, the concentration on command-and-control systems and computer simulations indicates a focus on optimizing military and defense operations through technology, improving decision-making in critical situations (cluster 2). It also highlights the growing concern for security and data privacy in an increasingly connected world, underscoring the need for strong authentication mechanisms and secure protocols (cluster 3). Likewise, incorporating artificial intelligence in cybersecurity reflects a move towards more dynamic and adaptive solutions to protect against complex and evolving threats in cyberspace (cluster 4). It also focuses on strengthening the security and efficiency of communications at the physical and network level, addressing challenges such as jamming and the vulnerability of critical communication infrastructures (cluster 5).

Along these lines, each identified cluster offers a perspective on cyberspace's various aspects and challenges, from information security to communication infrastructure, reflecting the broad spectrum of research and development in this dynamic field. In the space domain, the initial phase emphasizes establishing and improving fundamental space exploration and observation technologies. Period 2 reflects a concern for the environmental impact of space, human health in space, and technological development for Earth observation. Period 3 shows a growing interest in long-range exploration and understanding space's effects on life and technological systems. The most recent phase highlights the integration of emerging technologies to optimize the exploration and study of space, opening new possibilities for space analysis and management.

Throughout these periods, there is evidence of progression from the establishment of technological foundations and the study of space to the incorporation of advanced technologies and the exploration of new horizons in space, reflecting an ongoing commitment to expanding and deepening human knowledge of the universe. From the document linkage

networks in the cyberspace line, the presence of terms related to space research and technology reflects a growing interest in exploring Mars and other celestial bodies, with a strong focus on technological innovation to overcome the challenges of that environment (cluster 1). It also highlights the importance of innovative design and engineering in developing space technologies, focusing on adaptability and optimizing systems for space missions (cluster 2). Concerns about space debris and orbital safety underscore the critical need to develop effective methods for debris monitoring and management, ensuring the sustainability of future space missions (cluster 3). Similarly, it highlights the study and application of protective materials and technologies in space environments, crucial for the durability and safety of space structures against extreme conditions (cluster 4). The interest in understanding astronomical phenomena and the impacts of life and health in microgravity and radiation conditions is highlighted, underlying the importance of controlled studies for the safety of astronauts (cluster 5). Each cluster reveals a unique dimension of space research, from technology and system design to space debris management and life-in-space studies, reflecting the diversity and depth of this expanding field of study.

Limitations and future lines of research

The study employed databases that, although extensive, do not cover gray literature or internal technical reports of the armed forces, could omit relevant information that is not publicly available. Future research could expand the sources of information to include interviews with experts and analysis of internal documents, providing a more complete picture of technological and research development. It is proposed to explore how emerging technologies, such as machine learning and additive manufacturing, could influence operational efficiency and safety in air and space operations. Future research could focus on specific case studies within the Colombian Aerospace Force to evaluate the implementation and effectiveness of these technologies in real operational contexts.

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References

- Aeronáutica Civil (2020). *Foro Impacto del COVID-19 en el transporte aéreo*. <https://tinyurl.com/mun5rb66>
- Aguado-Montero, S., Navarro, C., Vázquez, J., Lasagni, F., Slawik, S., & Domínguez, J. (2022). Fatigue behavior of PBF additive manufactured Ti6AL4V alloy after shot and laser peening. *International Journal of Fatigue*, 154, 106536. <https://tinyurl.com/mycvanx8>
- Alves de Oliveira, L., Vendittozzi, C., & Kamchen M. (2022). *A key role for Brazil in international Orbital Debris detection and tracking Strategies*. Proceedings of the 73rd. International Astronautical Congress, IAC. <https://tinyurl.com/48txp27r>
- Antonopoulos, C. (2021). State responsibility in cyberspace. In N. Tsagourias & R. Buchan (Eds.) *Research Handbook on International Law and Cyberspace* (pp. 113–129). Edward Elgar Publishing.
- Campos Chaparro, C. A., Sequeda Ramon, J. N. D., Bejarano Cifuentes, I. X., & Jiménez-Sánchez, J. G. (2023). Misiones análogas espaciales como investigación para el desarrollo de ciencia y tecnología en la Fuerza Aeroespacial Colombiana. *Ciencia y Poder Aéreo*, 18(2), 6-19. <https://doi.org/10.18667/cienciaypoderareo.750>
- Castrillón Riascos, J. A., & Suárez Amador, C. A. (2024). Estado emprendedor y plan nacional de desarrollo, 2022-2026: oportunidades para la seguridad y defensa colombiana. *Ciencia y poder aéreo*, 19(1), 32-50. <https://doi.org/10.18667/cienciaypoderareo.800>
- Chávez, L. & Velásquez, S. (2017). Ejercicio del ciberpoder en el ciberespacio. *Ciencia y poder aéreo*, 12(1), 236-244. <http://dx.doi.org/10.18667/cienciaypoderareo.575>

- De Mol, M. L. (2023). Astrobiology in Space: A Comprehensive Look at the Solar System. *Life*, 13(3), 675. <https://doi.org/10.3390/life13030675>
- El-Sheimy, N., & Youssef, A. (2020). Inertial sensors technologies for navigation applications: state of the art and future trends. *Satellite Navigation*, 1(1), 2. <https://doi.org/10.1186/s43020-019-0001-5>
- Fuerza Aérea Colombiana (2020). Estrategia para el Desarrollo Aéreo y Espacial de la Fuerza Aeroespacial Colombiana 2042. FAC. <https://www.fac.mil.co/es/edaesfac2042>
- Gelularaj, B., Satwik, P., & Ashok Kumar, T. (2019). The Future of Cybersecurity: Major Role of Artificial Intelligence, Machine Learning, and Deep Learning in Cyberspace. In Smys, S., Bestak, R., Chen, JZ., Kotuliak, I. (Eds) *International Conference on Computer Networks and Communication Technologies, Lecture Notes on Data Engineering and Communications Technologies* (pp. 739–747). Springer. https://doi.org/10.1007/978-981-10-8681-6_67
- Hessel, V., Tran, N. N., Orandi, S., Asrami, M. R., Goodsite, M., & Nguyen, H. (2021). Continuous-Flow Extraction of Adjacent Metals - A Disruptive Economic Window for In Situ Resource Utilization of Asteroids? *Angewandte Chemie (International edition in English)*, 60(7), 3368-3388. <https://doi.org/10.1002/anie.201912205>
- Inamori, T., Hamaguchi, R., Ozawa, K., Saisutjarit, P., Sako, N., & Nakasuka, S. (2016). Online Magnetometer Calibration in Consideration of Geomagnetic Anomalies using Kalman Filters in Nanosatellites and Microsatellites. *Journal of Aerospace Engineering*, 29(6). [https://doi.org/10.1061/\(ASCE\)AS.1943-5525.0000612](https://doi.org/10.1061/(ASCE)AS.1943-5525.0000612)
- Jiménez González, A., Gómez Velasco, N., Ayala Sánchez, Y., & Guerrero, S. (2018). Estudio de la colaboración en publicaciones científicas. Facultad de Ciencias-UPTC, 2002-2014. *Saber, Ciencia y Libertad*, 13(1), 304-318. <https://dialnet.unirioja.es/descarga/articulo/6571920.pdf>
- Kavak, H., Padilla, J. J., Vernon-Bido, D., Diallo, S. Y., Gore, R., & Shetty, S. (2021). Simulation for cybersecurity: state of the art and future directions. *Journal of Cybersecurity*, 7(1), tyab005. <https://doi.org/10.1093/cybsec/tyab005>
- Khan, R., Tausif, S., & Javed Malik, A. (2019). Consumer acceptance of delivery drones in urban areas. *International Journal of Consumer Studies*, 43(1), 87–101. <https://doi.org/10.1111/ijcs.12487>
- Kolstoe, S. E., & Holden, L. (2020). Research Involving the Armed Forces. In R. Iphofen (Ed.) *Handbook of Research Ethics and Scientific Integrity* (pp. 603-621). Springer. https://doi.org/10.1007/978-3-030-16759-2_27
- Lemos, S. L., & Conde Rubiano, M. C. (2023). El Plan Nacional de Desarrollo 2022-2026: Colombia, Potencia Mundial de la Vida. *Revista Fasecolda*, 189, 64-69. <https://tinyurl.com/6ptfdh33>
- Leśnikowski, W. (2021). Threats from Cyberspace for Civil Aviation. *Wiedza Obronna* 276 (3), 124-153. <https://doi.org/10.34752/2021-h276>
- Miranda, F., Tedder, S., Vyhnalek, B., & Downey, J., Wroblewski, A., Bakula, C., Katz, E., Lekki, J., Dudukovich, R., Hylton, A., Raible, D. & Romanofsky, R. (2021). An overview of key optical communications technologies under development at the NASA Glenn Research Center. *Proceedings of SPIE 11692, Optical Interconnects XXI*, 130-144. <http://doi.org/10.1117/12.2579420>
- Morgan, F. E., Boudreaux, B., Lohn, A. J., Ashby, M., Curriden, C., Klima, K., & Grossman, D. (2020). *Military Applications of Artificial Intelligence: Ethical Concerns in an Uncertain World*. RAND Corporation. <https://tinyurl.com/4kp3c6vy>
- Nawrocki, M., Kurowski, K., & Gorzenski, R. (2021). Cyber Space and Aviation 4.0 – New Testing Facilities for Next Generation of Cyber-Physical, Autonomous and Air Traffic Control Systems. In P. Śniatała, S. Sitharama Iyengar, A. Bendarma, & M. Klósak (Eds.) *Modern Technologies*

- Enabling Safe and Secure UAV Operation in Urban Airspace* (pp. 70-84). IOS Press. <https://ebooks.iospress.nl/volumearticle/57205>
- Rahman, K., Aziz, M. A., Usman, N., Kiren, T., Cheema, T. A., Shoukat, H., Bhatia, T. K., Abdollahi, A., Sajid, A. (2023). Cognitive Lightweight Logistic Regression-Based IDS for IoT-Enabled FANET to Detect Cyberattacks. *Mobile Information Systems*. <https://doi.org/10.1155/2023/7690322>
- Rincon, R. F., Carter, L. M., Banting, R., Perrine, M., Du Toit, C. F., Steigner, P., Segal, K., Farrokh, B., Choi, M., Lu, D., Caruth, D., Ibanez, I., Khan, T., & Aberdeen, W. (2021). Recent Developments of the Space Exploration Synthetic Aperture Radar (SESAR) for Planetary Science Missions. *IEEE International Geoscience and Remote Sensing Symposium IGARSS, 7839–7842*. <https://doi.org/10.1109/IGARSS47720.2021.9554080>
- Saeed, N., Almorad, H., Dahrouj, H., Al-Naffouri, T. Y., Shamma, J. S., & Alouini, M.-S. (2021). Point-to-point Communication in Integrated Satellite-Aerial 6G Networks: State-of-the-art and Future Challenges. *IEEE Open Journal of the Communications Society*, 2, 1505–1525.
- Sloan, J. A., Stanford, S., Phelan, T. J., & Pocock, J. B. (2021). Infrastructure Truths for Air, Space, and Cyberspace. *Air & Space Power Journal*, 35(1). <https://tinyurl.com/2s3pxm9r>
- Srivastava, G., Jhaveri, R. H., Bhattacharya, S., Pandya, S., Rajeswari, M., P. K. R., Y., G., H., J. G., A., M., & Gadekallu, T. R. (2022). XAI for Cybersecurity: State of the Art, Challenges, Open Issues and Future Directions. *arXiv*. <https://doi.org/10.48550/arXiv.2206.03585>
- Urbina Carrero, J.C. (2017). El espacio, futuro de la Fuerza Aeroespacial Colombiana. *Ciencia y poder aéreo*, 12(1), 202-208. <https://doi.org/10.18667/cienciaypoderaaereo.572>
- Varadharajan, V., & Suri, N. (2024). Security challenges when space merges with cyberspace. *Space Policy*, 67, 101600. <https://doi.org/10.1016/j.spacepol.2023.101600>
- Vivian, E. C., & Marsh, W. L. (1921). *A history of aeronautics*. Harcourt Brace and Company.
- Voracek, D. F. (2020). *Research, Technology & Engineering 2019*. National Aeronautics and Space Administration (NASA). <https://tinyurl.com/8hufe22a>



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