Revista da UNIFA
revistaeletronica.fab.mil.br
https://doi.org/10.22480/rev.unifa.2026.39.1071
Artigo de revisão
e-ISSN 2175-2567

Science, technology and innovation in the brazilian aeronautical industry: a study of Embraer´s trajectory in technology transfer and patent development.

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ABSTRACT

This article explores the intersection of science, technology, innovation, and the history of aviation, focusing on the development of the Brazilian aeronautical industry and the pivotal role of Embraer. The primary objective is to analyze how technology transfer, intellectual property, and innovation have fueled the growth of Embraer and the broader Brazilian aeronautical sector. The research was conducted through a literature review and data analysis from the INPI database. The findings highlight that technology transfer was crucial for Embraer's evolution from a manufacturer dependent on foreign technologies to a global industry leader. International cooperation and investment in R&D enabled the absorption of knowledge and the development of proprietary projects. Currently, the industry faces new challenges, such as the need for sustainable technologies.

Keywords: *Embraer; Technology Transfer; Aeronautical Industry; Intellectual Property.*

Ciência, tecnologia e inovação na indústria aeronáutica brasileira: um estudo sobre a Embraer e sua trajetória de transferência de tecnologia e desenvolvimento de patente.

RESUMO

A intersecção entre ciência, tecnologia, inovação e a história da aviação, com foco no desenvolvimento da indústria aeronáutica brasileira e no papel da Embraer é o objeto deste artigo. O objetivo é analisar como a transferência de tecnologia, a propriedade intelectual e a inovação impulsionaram o crescimento da Embraer e da indústria aeronáutica brasileira. A pesquisa foi realizada com revisão bibliográfica e análise de dados obtidos na base do INPI. As conclusões destacam que a transferência de tecnologia foi fundamental para a Embraer evoluir de uma fabricante dependente de tecnologias estrangeiras para uma líder global no setor. A cooperação internacional e o investimento em P&D permitiram a absorção de conhecimentos e o desenvolvimento de projetos próprios. Atualmente, a indústria enfrenta desafios como a necessidade de tecnologias sustentáveis, exigindo inovação contínua para manter a competitividade global.

Palavras-chave: *Embraer; Transferência de Tecnologia; Industria Aeronáutica; Propriedade Intelectual.*

Ciencia, tecnología e innovación en la industria aeronáutica brasileña: un estudio sobre Embraer y su trayectoria de transferencia de tecnología y desarrollo de patente.

RESUMO

La intersección entre ciencia, tecnología, innovación e historia de la aviación, con énfasis en el desarrollo de la industria aeronáutica brasileña y el rol de Embraer, es el tema de este artículo. El objetivo es analizar cómo la transferencia de tecnología, la propiedad intelectual y la innovación han impulsado el crecimiento de Embraer y de la industria aeronáutica brasileña. La investigación se realizó mediante una revisión bibliográfica y el análisis de datos obtenidos de la base de datos INPI. Las conclusiones destacan que la transferencia de tecnología fue fundamental para que Embraer evolucionara de un fabricante dependiente de tecnologías extranjeras a un líder mundial en el sector. La cooperación internacional y la inversión en I+D permitieron la absorción de conocimiento y el desarrollo de sus propios proyectos. Actualmente, la industria enfrenta desafíos como la necesidad de tecnologías sostenibles, que requieren innovación continua para mantener la competitividad global.

Palabras clave: *Embraer; Transferencia de Tecnología; Industria Aeronáutica; Propiedad Intelectual.*

1 INTRODUCTION

The Brazilian aeronautical industry represents one of the nation's strategic economic sectors, known for its capacity for innovation, technological development, and significant contributions to science. From its early stages in the 20th century to the consolidation of globally renowned companies like Embraer, Brazil has demonstrated a remarkable trajectory of advancements and achievements in this field.

This article explores the intersection of science, technology, innovation, and the Brazilian aeronautical industry, using the history of aviation as a guiding thread. This analysis aims to understand technological innovations in Brazilian civil aviation, examining how technology transfer fosters scientific and technological progress for the sector's development. By examining this intersection, we can better understand its evolution and the challenges and opportunities that have emerged over time. By analyzing scientific and technological development, we intend to highlight how the sector has established itself as a fundamental pillar in promoting the country's economic and social progress, as well as its insertion into the international arena.

The objective of this article is to analyze how technology transfer, intellectual property, and innovation have driven Embraer's growth. Thus, it seeks to answer the question: "How have technology transfer and patent development by Embraer contributed to scientific, technological, and innovative advancements in the Brazilian aeronautical industry?"

1.1 Science, Technology, and Innovation

The term science can be employed as a synonym for learning or knowledge; however, in a stricter sense, it can be regarded as a special form of knowledge—scientific knowledge—as opposed to other forms, such as common sense (Carlos Barbieri, 1990). Scientific knowledge is characterized by being factual, systematic, verifiable, fallible, and permeated by a high degree of precision (Marconi; Lakatos, 2017). In this context, science is also understood as the activity intentionally directed toward the production of this scientific knowledge (Carlos Barbieri, 1990). This objective, in turn, can be achieved through observation and experimentation, among other methods.

Still, regarding the concept of science, there is a basic distinction between pure science and applied science. The former is concerned with acquiring new knowledge without immediate practical objectives. Conversely, applied science aims to utilize existing knowledge to solve identified practical problems (Carlos Barbieri, 1990). In the aeronautical realm, as discussed in this study, both forms of science are present.

From its Greek etymology, "technology" can be understood as the application of knowledge or methods to achieve an objective (Carlos Barbieri, 1990). It goes beyond scientific knowledge; it encompasses the set of practical skills to create, execute, and adapt solutions (Veraszto *et al.*, 2009) that enable the utilization of material resources for productive ends (Fontes, 2011, p. 276). Modern technology, grounded in science, differs from traditional technology, which was empirical and developed over generations, as observed in early times (Carlos Barbieri, 1990). It emerges from social needs; thus, one should not view technology as an independent entity, but rather as intrinsically connected to society and culture. As a cultural element, it reflects the values of its developers and, when introduced into new contexts, can influence or even dominate local cultural aspects (Veraszto *et al.*, 2009).

In aviation, given its numerous practical challenges, technology is essential from design to aircraft manufacturing, air traffic management, and operational safety. Permeating the process from conception to mass production, it evolves continuously, driven by demands for efficiency, safety, and competitiveness. Examples include computational simulations, which enable aerodynamically efficient and safe aircraft; innovative materials that increase resistance and reduce weight, improving performance and energy efficiency; embedded systems that ensure safety and efficiency; and automated flight control, satellite navigation, and real-time data analysis, which allow for monitoring aircraft performance and anticipating potential problems before they become critical. In short, these essential technologies in modern aircraft place the aeronautical sector at the forefront of technological development.

Science and technology are distinct concepts that should not be confused. Although technology utilizes available scientific knowledge, it is not restricted to it alone. Basic science seeks knowledge without concern for immediate application, whereas technology constitutes fundamentally utilitarian knowledge, aimed at intervening in nature (Carlos Barbieri, 1990, p. 12).

The term "technological innovation" refers to Schumpeter and his concept of "creative destruction" — that is, the replacement of existing technologies by those with disruptive potential. The author "[...] through his studies on economic development, proclaimed that economies would be increasingly affected by 'creative destruction' based on the replacement of technologies in use by those with the power of rupture" (Plaza; Santos, 2011, p. 176). This process may face resistance from non-innovative companies, whether because they feel threatened or because they are reluctant to cooperate. "In economic matters, this resistance manifests itself first of all in the groups threatened by the innovation, then in the difficulty in finding the necessary cooperation, finally in the difficulty in winning over consumers" (Schumpeter, 1997, p. 93).

As early as the 1930s, Schumpeter addressed the advantage of innovative entrepreneurs over others, and subsequently emphasized the relevance of technological progress for economic development (Carlos Barbieri, 1990). His studies evidenced innovation as the engine of economic growth and competitiveness, allowing innovative companies to improve products and processes, open new markets, and establish benchmarks.

According to the Oslo Manual (2018), innovations derive from knowledge-based activities. In this context, two concepts are relevant: information and knowledge. The former consists of organized data, easily reproducible and transferable between organizations at low cost. Knowledge, on the other hand, refers to the understanding of information and the ability to apply it for various ends. Acquired through cognitive effort, knowledge transfer is more complex, requiring learning on the part of the receiver. Both information and knowledge can be obtained or created internally or externally to an organization.

Innovation begins with the conception of an idea and its movement toward the creation of a product or process that is commercially successful and competitive (Terra, 2001, p. 1).

Science, research, and technological innovation are intrinsically connected, making it difficult to separate them. Research and Development (R&D) comprises investigative procedures based on theoretical analyses in various areas of Science and Technology (S&T), now integrated into innovation within the concept of Research, Development, and Innovation (R&D&I) (TERRA, 2001, p.12). It is important to highlight that intellectual property constitutes an efficient mechanism for the total or partial transfer of knowledge between organizations and individuals, fostering the development of inventions and innovations. In patents, for example, the State grants property rights to the creator of an industrially applicable novelty. In trade secrets, know-how is protected by organizational strategies and industrial counter-espionage measures (Carlos Barbieri, 1990, p. 37).

However, from the innovation standpoint, these technological advances, knowledge, and protection mechanisms only have value when converted into monetary gains, transforming inventions into real innovations. It is worth noting that determining with precision and in advance the potential economic benefits that specific knowledge may provide is complex (Avila, 2011, p. 88).

1.2 Survey of new data cited in this article

In this work, data from Embraer, the leading company in the sector in Brazil, were analyzed. Methodologically, a qualitative approach was chosen, enabling an in-depth exploration of the processes and meanings underlying the portfolio of patent rights and technology transfer agreements registered with the INPI (National Institute of Industrial Property). This methodology allows for capturing the complexity and richness of the studied phenomena, considering the context and the nuances involved (Hernández Sampieri; Fernández Collado; Del Pilar Baptista Lucio, 2013).

The research is also exploratory in nature, as it seeks to build new knowledge in a field of study not yet consolidated, aiming to obtain a comprehensive view of the themes in question and to identify areas for future investigation. To this end, data collection was performed through a bibliographic and documentary review, analyzing primary and secondary sources, including legislation, filed patents, technical reports, and scientific publications.

At the beginning of the process, data were collected from the INPI and ORBIT databases, which store information on patents and technology transfer agreements.

For patents, a search was conducted in the INPI database using the keyword "Embraer" in the specific name field, with the parameters "contains all words" and in the "applicant name" (*nome do depositante*) field. Using the search parameters EMBRAER/TX/BI/SA/KEYW/IN/PA on the ORBIT platform, a snapshot of the patent landscape was captured as of August 2, 2023. The resulting dataset underwent manual filtering to exclude any patents not directly pertinent to the aeronautical industry.

The data obtained were then organized and recorded in spreadsheets, forming a database. This step was crucial for structuring the data according to relevant information, such as patent title, description, application number, grant date, parties involved in the contracts, IPC, among other variables. During this process, verifications were carried out to ensure data consistency and integrity, correcting potential errors or inconsistencies, including the exclusion of outliers. It is important to mention that no distinction was made between invention patents and utility models; both were treated under the general category of patents. Finally, the patents filed by Embraer and analyzed in this study reflect only the inventions developed by the company. It should be emphasized that not all patented inventions transform into innovations and that not all inventions were the subject of patent filings.

Regarding the technology transfer agreements registered with the INPI, the period was limited from January 10, 2013, to August 2, 2023, totaling a timeframe of over 10 years. The search on the INPI platform was performed using the term "Embraer" in the "assignee name" (*nome da cessionária*) field, using the parameter "contains all words." In the following step, the period was limited to August 2, 2023, searching for the term "Embraer" in the "assignor name" (*nome da cedente*) field, using the parameter "contains all words."

The indicated timeframe is justified because the 10-year period represents a milestone aligned with current industry realities while encompassing various phases of the researched company. In this sense, the timeframe also covers potential changes in the company's strategies, such as expansion into new markets and the development of new products. Finally, this limitation is also related to the feasibility of the research itself, as analyzing contracts registered since the company's foundation would make the research unfeasible due to the volume of data.

Still within the scope of research limitations, it is worth noting that the technology transfer agreements analyzed in this study are limited to those registered with the INPI. This means they may not represent the totality of agreements signed by Embraer, given the possibility of contracts that are not registered in the INPI database or are confidential. Furthermore, it is important to highlight that these records do not cover intra-firm technology transfers—that is, those occurring internally between units or subsidiaries of the same company.

Subsequently, the tabulated data were imported into Power BI software, a powerful data visualization tool. In Power BI, interactive dashboards were created to enable the mapping and analysis of data from various perspectives, allowing for a numerical overview of the studied object.

Having said that, it should be noted that the article is organized into two sections. The first addresses the relationship between the concepts presented in this introduction and the history of aviation, conducted from the perspective of science, technology, and innovation. The second topic, still following this historical line, deals with the development of intellectual property and technology transfer at Embraer.

2 THE EVOLUTION OF AVIATION: SCIENCE, TECHNOLOGY, AND INNOVATION

Since antiquity, the human desire to fly has manifested itself in various cultures, from Greek mythology with the myth of Icarus and Bellerophon to Indian mythology with the Vimanas. However, the first significant advances in understanding aerodynamic forces were made during the Renaissance, when Leonardo da Vinci (1452-1519) designed flying machines based on natural observations, although not all were built at the time (Silva; Santos, 2009).

It was Da Vinci who arguably presented one of the first empirical studies of aerodynamics, investigating how wings interact with the air to generate lift. Such studies were fundamental for subsequent developments. The prototyping technique used in the early days of aviation is today widely recognized and scientifically validated for proofs of concept, although it was initially applied as mere experimentation without current scientific rigor (Silva, 2017).

In the 17th century, Giovanni Borelli advanced the study of flight by analyzing the biomechanics of birds, albeit without immediate practical results. The 18th century witnessed the first manned flight with the Montgolfier brothers' hot air balloon in 1783. In the 19th century, the development of the glider by pioneers such as Otto Lilienthal constituted a significant advance, establishing the foundations for controlled flight (Trueva, 2017).

During the 19th century, while the focus on lighter-than-air aircraft predominated, proponents of heavier-than-air machines were considered utopian. Even so, these pioneers, demonstrating scientific potential, followed two lines of research: aircraft with flapping wings similar to birds and the concept of fixed wings utilizing propulsors (Schmitt; Gollnick, 2016).

In France, Alphonse Pénaud designed an innovative amphibious aircraft in 1876, limited by the absence of suitable lightweight engines. Clément Ader built the *Éole*, a steam-powered monoplane that flew 50 meters in 1890, and subsequently attempted the *Avion* project, which was frustrated by financial constraints. Between 1850 and 1900, significant advances occurred in several countries, including Brazil, Australia, the United Kingdom, and the USA (Schmitt; Gollnick, 2016).

In 1906, Alberto Santos Dumont (1873-1932), known for creating steerable airships (series N1-10), performed the first public homologated flight of a heavier-than-air machine (14-Bis), taking off without external assistance and initiating the aviation of self-propelled vehicles.

Despite successive progress and prior military use—in the Italo-Turkish War of 1911—it was only during World War I (1914-1918) that aviation evolved from a curiosity into a strategic weapon, with the development of combat aircraft and bombers. The conflict accelerated research in aeronautical technology, resulting in faster, relatively safer, and more maneuverable aircraft.

The interwar period witnessed the development of larger and more powerful commercial and military planes. In 1935, with the introduction of the "Küssner point"[1], an empirical formula based on reduced torsional frequency (ub/V)[2] established criteria for estimating flutter speed[3] in the various types of aircraft existing at the time (Garrick; Reed, 1981), culminating in jet aviation, with the first flight of a jet-powered aircraft performed by Germans in 1939 (Lima, 1980). In 1938, a 1/4-scale wing model of the PBM-1 was tested

[1] The Küssner point (or Küssner function) relates to aeroelasticity and the transient effect of wind on aircraft, known as "step response." It describes the aircraft's reaction to abrupt changes in flight conditions, such as entering wind gusts. This mathematical instrument is crucial for understanding the temporary response of aircraft to gusts, ensuring predictability and safety in adverse conditions (GARRICK; REED, 1981).

[2] Reduced torsional frequency is a fundamental parameter in aeroelasticity, used to analyze the interaction between aerodynamic forces and the aircraft structure, particularly in phenomena such as flutter. It helps predict the critical flutter speed, at which unstable oscillations may begin. By non-dimensionalizing the frequency, engineers apply the concept to different aircraft to predict aeroelastic responses under various flight conditions (GARRICK; REED, 1981).

[3] Flutter speed is the critical velocity at which an aircraft experiences a dangerous aeroelastic phenomenon. Flutter constitutes a self-excited and unstable oscillation resulting from the interaction among aerodynamic forces, structural stiffness, and inertial forces. If reached without adequate measures, it can cause severe structural damage rapidly, leading to catastrophic failures such as the destruction of wings, tails, or control surfaces (GARRICK; REED, 1981).

in the NACA Propeller Research Tunnel by researchers Felix Nagel, William Bergen, Rene H. Miller, and Edwin P. Hartman.

Another relevant event was World War II (1939-1945), during which advances such as the use of polyvinyl chloride (PVC) became popular for prototype construction due to its moldability. With lower density and elasticity than full-scale aluminum, it allowed for models geometrically similar to the prototypes. In 1942, the Vultee XP-54 model was tested, and in 1944, in Germany, a complete aeroelastic model of the Junkers JU-288. These tests guided design variables such as control surface stiffness and stabilizer connection (Garrick; Reed, 1981).

It is observed that, over time, these practices and technological developments were disseminated and improved by researchers and manufacturers worldwide. For example, wind tunnel tests[4], whose earliest instance identified in this study dates to 1942, continue to be employed by all modern aircraft manufacturers. In parallel, advanced 3D modeling systems are currently used by manufacturers in project development.

After World War II, jet aviation established itself as the standard for military and commercial purposes. In the 1950s and 60s, commercial jets like the Boeing 707 revolutionized air transport, making intercontinental travel faster and more accessible. Military aviation progressed with supersonic aircraft and, subsequently, stealth fighters. Currently, the sector faces challenges such as the development of sustainable technologies, including electric aviation and autonomous aircraft (Lima, 1980; Trueva, 2017).

From the Great War to the 1950s, aviation continued its technological evolution using wind tunnel models to validate theories, especially regarding flutter, following the aforementioned line. Concurrently, scientific techniques themselves were improved, seeking greater precision in wind tunnel tests (Garrick; Reed, 1981). During this period, individuals and companies began to develop their own know-how to conduct these tests. With the advancement of aviation, the application of wind tunnel tests, mathematical analysis of aerodynamics, and the development of lighter and stronger materials intensified.

It is noteworthy that aeroelastic effects were utilized, and possibly scientifically understood, by Orville and Wilbur Wright in their biplane to control flight without the need for ailerons (Garrick; Reed, 1981). "They also were aware of the adverse aeroelastic effect of the loss of thrust of a propeller, due to twisting of the blades, by their experiments on the performance of thin propellers having broad blades" (Garrick; Reed, 1981, p. 898). In other instances, catastrophes such as that of the first commercial jet[5], the COMET, produced by the British company de Havilland, science advanced in the understanding of aeronautical material fatigue and fuselage design to identify the causes of disasters (Schmitt; Gollnick, 2016b, p. 29).

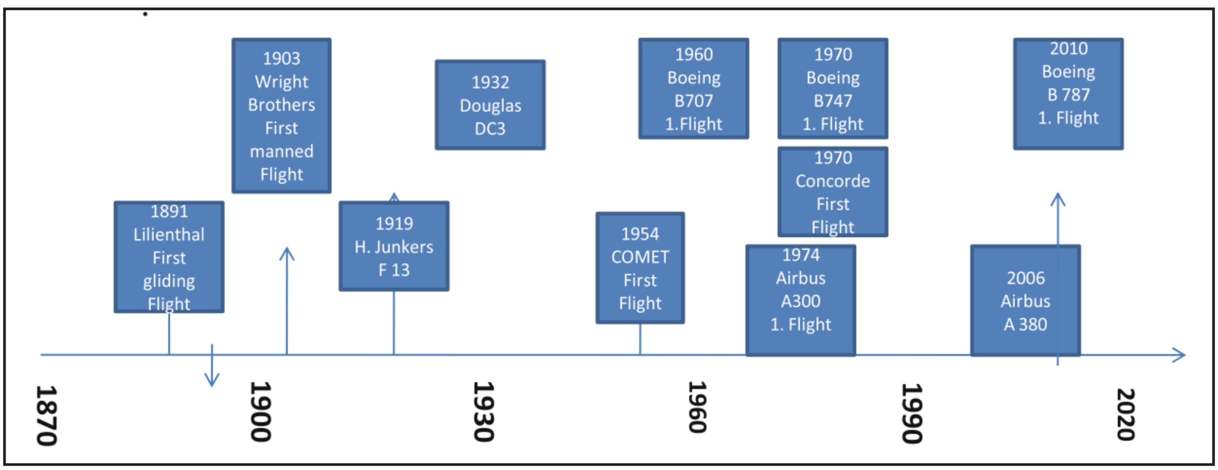
[4] A wind tunnel is a facility that simulates airflow around objects such as aircraft, rockets, or cars to study their aerodynamic properties. It allows engineers and scientists to evaluate air behavior around scale or full-size models, providing crucial data on lift, drag, turbulence, and control (CLAUDINO, 2014).

[5] Two tragedies involved the COMET jets. The first occurred on January 10, 1954, when the aircraft registered G-ALYP, operated by the British Overseas Airways Corporation, disintegrated during the climb to cruise level. A similar incident happened to the aircraft registered G-ALYY on April 8, 1954, which led authorities to revoke the model's certificate of airworthiness. (OLÍMPIO, 2022).

With this expertise established, the global aeronautical industry entered the era of jet engines. The evolution of aviation, however, is not limited to aircraft development, also encompassing aeronautical infrastructure, such as aerodromes, and airlines (Schmitt; Gollnick, 2016).

The history of aviation, although dating back to antiquity, only assumes its current form from the 1900s onwards, as mentioned. The timeline in Figure 1 summarizes technological development through milestones such as the Wright Brothers' flight (1903), Santos Dumont's 14-Bis (1906), the COMET (1954), the Boeing 707 (1960), and so forth, highlighting the remarkable technological evolution from the Wrights' experimental flight to the emergence of the Airbus A380, the world's largest passenger aircraft.

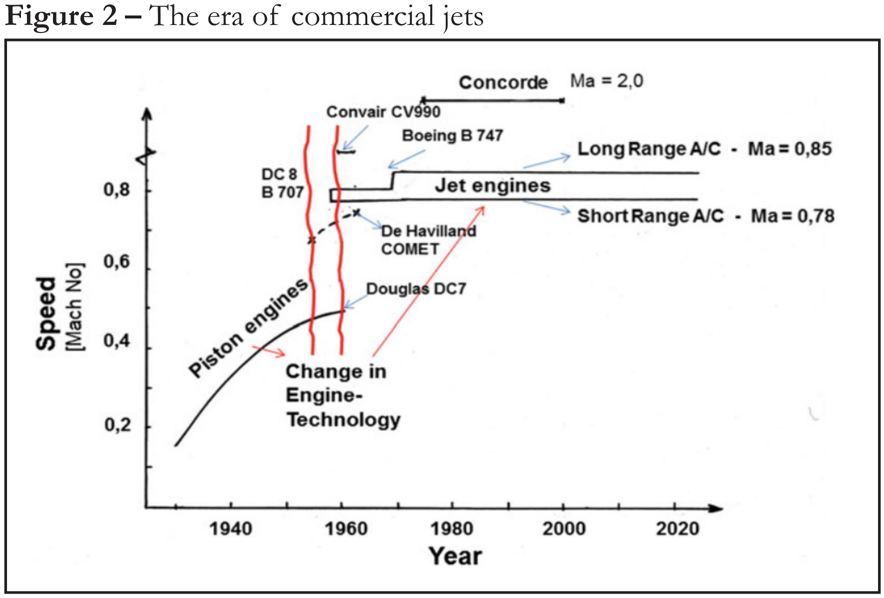
Figure 1 – Aviation evolution timeline



Source: SCHMITT, GOLLNICK, 2016.

Next, Figure 2 demonstrates the evolution of aeronautical technology in relation to flight speed, marking the era of jet engines, distinguishing between short-haul and long-haul aircraft, and highlighting the Concorde milestone.

Figure 2 – The era of commercial jets



Source: SCHMITT, GOLLNICK, 2016.

Figure 2 illustrates that a paradigm shift occurred between 1955 and 1960. Until then, piston-engine aircraft predominated, with the Douglas DC-7 being the last model of this category. The De Havilland COMET inaugurated the jet engine era, followed by the DC-8 and Boeing 707, marking a fundamental transition from internal combustion piston engines to the jet engines used today.

Entry into the jet age not only represented a technological advance in aircraft but also drove the development of aeronautical infrastructure and airlines. Aerodromes evolved to meet the demands of larger and faster aircraft, while airlines refined their management to balance high operational costs with the maximization of seat occupancy.

This trajectory reflects not only technical advances but also the increasing complexity and sophistication of the industry. As will be presented subsequently, the Brazilian aeronautical industry also underwent its own development process until its consolidation.

2.1 Formation of the Brazilian Aeronautical Industry

The inception of the Brazilian aeronautical industry relied on the importation of foreign technologies, including Embraer, whose trajectory is often intertwined with the history of the sector itself in Brazil. This industry encompasses public and private companies dedicated to the research, development, manufacturing, and marketing of aircraft and components (Irene Von Der Weid, 2022).

The initial milestone was the creation of the Aerospace Technical Center (*Centro Técnico Aeroespacial* - CTA), a network of laboratories and institutions with distinct technological capabilities. "In this way, a structure was created capable of enabling not only the aircraft research and development process but also the aircraft production process itself, utilizing strong public incentive for this purpose" (Oliveira, 2005). The CTA, currently the Department of Aerospace Science and Technology (DCTA), is a military organization of the Aeronautics Command that plans, manages, and controls science, technology, and innovation activities within the Brazilian Air Force (Museu Aeroespacial da FAB, [n.d.]).

In 1942, the first class of aeronautical engineers graduated, having been transferred to the newly created Ministry of Aeronautics. In 1945, Colonel Casimiro Montenegro Filho visited the USA and, together with Prof. Richard Smith from MIT, established the project to create the CTA in São José dos Campos. In 1946, the Organization Commission of the Aerospace Technical Center (COCTA) was created, which was extinguished in 1953 when the CTA was officially organized by Decree No. 34,701 (Museu Aeroespacial da FAB, [n.d.]).

The structure of the CTA, composed of independent institutes (IFI, IAE, IEAv, and ITA)[6], created a favorable and synergistic environment for the formation of intellectual capital and the production of technologies. These elements culminated in the production of high-quality and globally competitive aircraft (Oliveira, 2005), as noted by Correa (2017, p. 14), stating that Embraer, "currently one of the largest aircraft manufacturers in the world, was born as a state-owned enterprise from the structure of the CTA."

[6] IFI – R&D; IAE – Research and development of technologies; IEAv – promotion and support; and ITA – Education and training (OLIVEIRA, 2005, p. 75).

Despite Dumont's pioneering spirit, in this context, it is observed that the formation of this sector in Brazil only occurred after World War II, with all the technological implications previously reported. The formation and consolidation of an industrial sector so strongly based on science and technology, and with such exponential development, was only possible through the absorption of external knowledge. Thus, technology transfer played a fundamental role in the sector's development and competitiveness. Even with the creation of the CTA and its synergy with Embraer, the initial knowledge acquired through technological packages and offset agreements signed between the CTA/Ministry of Aeronautics (MAER) and international partners was fundamental.

It is important to highlight the role of offset agreements in the internalization of competencies. These agreements are implemented as extensions of commercial contracts, forming additional benefit packages for the acquirer. They generally involve commitments from the supplier (often foreign) to generate positive impacts in the purchasing country through technology transfer, industrial investments, supplier development, or workforce training (Correa, 2017). In Embraer's case, these agreements played a strategic role in consolidating the company as a global leader in the aeronautical sector, simultaneously contributing to the development of the Brazilian industry (Correa, 2017).

In the first phase of collaboration between CTA and Embraer, several aircraft were developed: Bandeirante – EMB110/111 (1971-1992), Ipanema – EMB 200/200 A (1971), Xavante – EMB 326 (1971-1981), Piper Line (1975), Xingu – EMB121 (1978-1987), Brasília – EMB120 (1985), Tucano – EMB312 (1983), AMX (1989), Vector CBA123 (1989), and ERJ 145 (1989) – all crucial for learning, training, and the absorption of foreign technologies. In the second phase, the company developed the ERJ 140, ERJ 135, Legacy, 170, 175, 190, and 195 projects (Oliveira, 2005).

It is worth noting that the Bandeirante, Embraer's first product, only became viable thanks to know-how imported through technical assistance from the Italian manufacturer Aermacchi. This technology transfer was one of the conditions for the acquisition of the MB 326 (Xavante) military aircraft. The main benefits of this transfer included the improvement of manufacturing processes, technology for jet engine integration, development of tools for mass manufacturing, and the elaboration of technical manuals (Netto, 2005).

Incremental innovation predominated with the absorption of imported technologies that were subsequently improved. In aerodynamics, for example, technologies initially acquired via NASA blueprints underwent increments through computational development. After privatization (1994), the 170 family project involved intense R&D with partners such as ITA, TsAGI (Russia), Cranfield/ETPS (United Kingdom), and EPNER (France) (Oliveira, 2005).

In production, licensing agreements with Aermacchi, Northrop, and Piper allowed Embraer to develop expertise in coordinating risk-sharing partners and supply chain management. The company absorbed and improved quality control and productive organization, becoming a specialist in aircraft integration and assembly. The cooperation with Piper during the development of the Bandeirante established at Embraer the routine of following international certification standards, a procedure that became standard in more recent models, including the 170 family (Oliveira, 2005).

It is evident that technology transfer to the Brazilian aeronautical sector transcends the aircraft itself, encompassing fundamental processes such as the structuring of the CTA, an essential technological source for Embraer to this day, and the company's internal manufacturing processes.

Having overcome the initial stages, Embraer, now consolidated, began to develop and adopt advanced technologies instead of merely importing them (Motor Show, 2024). Companies that adopt such technologies manage to create more efficient aircraft, reducing operational costs and increasing competitiveness, rather than merely keeping already mastered technologies in production and losing market share.

However, the technologies embedded in hardware, software, designs, and all aircraft systems form a comprehensive technological package; isolated developments in Brazilian aeronautical technology alone would not suffice to make the industry globally competitive.

> Thus, in the elaboration of a [technological] package, what matters is selecting and utilizing its various components (knowledge from various sources) in order to achieve the expected results. Therefore, it does not matter whether such components are original or not, scientific or not, produced through one's own effort or acquired from others, based on recent inventions or on old technologies, etc." (Sá Bato and Marckennzie, 1981, *apud* Carlos Barbieri, 1990, p. 20, translated by author).

The technology produced by Embraer not only determines the company's economic efficiency but is also decisive for its competitiveness, reflecting directly on the company's revenue and profit (Carlos Barbieri, 1990, p. 21).

Moving to another line of argument, invention is the starting point for innovation, but not all inventions transform into commercial innovations. The Brazilian aeronautical sector began through incremental innovations based on technology transferred from abroad, this being the main impact of such transfer. The Oslo Manual (2018, p.20) does not differentiate between product and process innovation. Thus, it is expected that, driven by technology transfer, Embraer will continue generating inventions and innovations for the national aeronautical industry.

The interaction between history and aviation reveals a dynamic process where technology transfer is fundamental for aeronautical evolution. The Brazilian sector, which began manufacturing under licensing and benefited from offset agreements, finds in Embraer an example of how innovations, even incremental ones, are vital for competitiveness. According to the Oslo Manual (2018), the ability to adapt and improve technologies through international partnerships and the absorption of external knowledge is essential for developing new products and processes. This interaction between historical and technological elements not only fosters innovations but also positions the Brazilian aeronautical sector on a growth trajectory aligned with global demands.

3 INTELLECTUAL PROPERTY AND TECHNOLOGY TRANSFER: PILLARS OF TECHNOLOGICAL DEVELOPMENT IN THE BRAZILIAN AERONAUTICAL INDUSTRY

Intellectual property (IP) and technology transfer (TT) are indispensable for innovation and competitiveness. IP is fundamental for ensuring a return on investment by allowing companies to recover investments through patents, while proprietary know-how offers a competitive advantage that is difficult to replicate. TT, in turn, enables cooperation between agents and accelerates technological development.

As previously mentioned, the first aeronautical technologies were brought to Brazil primarily by the Ministry of Aeronautics. In this context, for Embraer, the establishment of partnerships with national institutions (such as the CTA) and international companies was essential for the acquisition, incorporation, and adaptation of advanced technical knowledge. The result was globally competitive products, achieved both through manufacturing under license and the development of proprietary projects, thereby strengthening the national aeronautical industry.

3.1 IP Regulation

At the international level, IP is regulated by various treaties. The Paris Convention for the Protection of Industrial Property (Paris Convention), of 1883, was the first on the subject and is currently adopted by more than 180 countries, including Brazil (WIPO, 1998). This document harmonizes IP legislation without unifying it, guaranteeing national legislative freedom. Its success is based on territoriality, national treatment (parity between nationals and foreigners), the priority principle (a 12-month period for filing in other countries), and the independence of patents (decisions in one country do not affect other members) (Gontijo, 2005).

The Patent Cooperation Treaty (PCT), signed in 1970 and in force since 1978, is administered by the World Intellectual Property Organization (WIPO). It facilitates the international verification of the novelty of inventions, meeting the requirement of absolute novelty. Designated offices conduct searches in international databases and issue a written opinion (França, 2007).

Consequently, the TRIPS Agreement, signed in 1994 within the scope of the World Trade Organization (WTO), establishes minimum standards of protection for various forms of IP and requires effective procedures for the enforcement of these rights, playing a fundamental role in the international harmonization of IP norms. Since its entry into force, TRIPS has directly impacted national laws and the interaction between domestic and international norms (Barbosa, 2003).

Considering the chronology of international IP treaties—Paris Convention (1883), PCT (1978), and TRIPS (1994)—it is noted that the entire technological revolution of jet engines and the beginning of the Concorde's supersonic flights occurred under the exclusive regulation of the Paris Convention. Although other factors may be considered, this suggests the efficacy of this first treaty in promoting innovation and protecting Industrial Property during that period, demonstrating that significant technological advances in aviation happened independently of the subsequent modernization or harmonization of IP legislation. The relationship between legislation and the technological paradigm shift suggests that aeronautical innovation did not depend directly on the modernization of IP norms but was enabled by the Paris Convention's capacity to provide a secure environment for intellectual protection, despite being a norm from 1883. This demonstrates that this regulatory framework was sufficiently effective to ensure the confidence necessary for R&D investments in a highly complex sector.

Alternatively, it can be argued that aeronautical innovation operates partially independently of regulation, considering that significant advances such as the transition to jet engines occurred when the Paris Convention was the sole international instrument for IP protection, prior to the PCT or TRIPS. This indicates that innovations can be driven by factors external to legislation, such as market demand, global competition, scientific advances, and the companies' capacity to apply new knowledge. Another point to be highlighted is the fact that, as this involves relevant military-use technology, wars and arms races also played an important role in this progress.

However, this does not diminish the importance of international IP treaties. The analysis reinforces that, although innovation can occur in less complex normative scenarios, a robust and contemporary IP system is essential to guarantee the protection of inventors' rights. The Paris Convention, by establishing principles such as national treatment, priority, and the independence of rights, created the foundations for these technological advances.

In Brazil, in 1830, even before the Paris Convention, the country published a norm—the Law of August 28, 1830—granting privileges to anyone who discovered, invented, or improved any item with industrial application (Brasil, 1830). Subsequently, Law 5,772/71, known as the Industrial Property Code, was published (Brasil, 1971). Finally, the current Law 9,279/96, amended by Law 14,852/24, regulates rights and obligations related to industrial property (Brasil, 1996). Thus, it can be seen that Embraer was founded approximately 2 years before the entry into force, on December 31, 1971, of Law 5,772/71 (Industrial Property Code). Therefore, all intellectual property produced by the company until May 15, 1997, the date the current industrial property law came into force, would be under the aegis of the aforementioned code.

The modernization of intellectual property laws and adherence to international treaties such as the TRIPS Agreement positively affect the protection of and promotion for technological innovation, mainly through the possibility of monetization of protected innovations. This regulatory framework stimulates R&D investments and fosters international cooperation and technology transfer.

3.2 Period 1950-1970

The creation of the CTA (1947), ITA (1950), and Embraer (1969) fostered Brazilian industrial growth. "However, the fragility of the companies' technological base was the main obstacle to the country's industrialization and economic development process" (Terra, 2001, p. 138). Overcoming this technological deficiency was possibly Embraer's great merit, made possible by the extensive support from the CTA. This center provided the technological base and human resources that allowed for the effective absorption of imported technologies through contracts with foreign organizations in subsequent years.

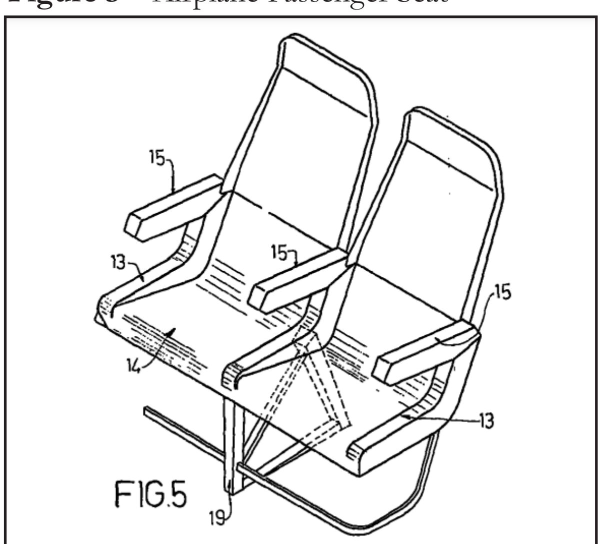
By 1968, the CTA had already developed two aircraft: the EMB 400 Urupema glider, which performed its first flight in January, and the EMB 100 Bandeirante. The Bandeirante, the first aircraft produced by the future Embraer, equipped with a turboprop engine and capacity for 8 passengers and 2 crew members, made its maiden flight on October 22, 1968, remaining in production until 1970 (Embraer S.A., 2022). It can be inferred that these two initial projects in partnership with the CTA established the technological foundations that enabled Embraer to effectively absorb imported technologies.

3.3 Period 1970-2000

On April 2, 1976, Embraer signed a technical-industrial cooperation agreement with Northrop Corporation (USA), registered under application 760619 and protocol 1052292. Subsequently, on September 21, 1978, another technical and scientific assistance contract was signed with Northrop, identified by application 782298 and protocol 1047227. These contracts evidence the strategy of utilizing international TT agreements to acquire and adapt knowledge. Since the 1980s, the company has been acquiring peripheral technologies or consultancy services to develop proprietary solutions and solve problems identified during project development.

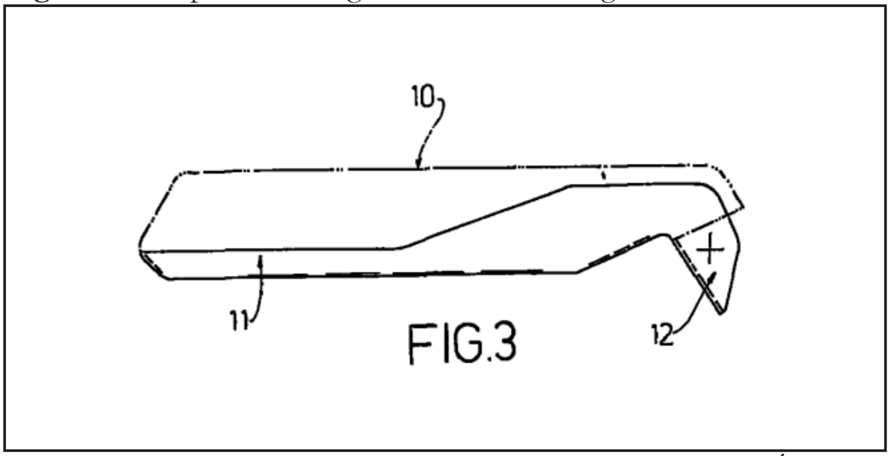
However, from its foundation until May 15, 1997, Embraer filed only two patents, both on July 17, 1986, classified under IPC A47C: the 'Passenger Seat in Airplanes' (*Assento De Poltronas De Passageiros Em Aviões* - PI 8603369-7 A2) and the 'Articulated Arm for Passenger Seat' (*Braço Articulável Para Poltrona De Passageiros* - PI 8603370-0 A2), as illustrated in Figures 3 and 4.

Figure 3 – Airplane Passenger Seat



Source: EMBRAER EMPRESA BRASILEIRA DE AERONÁUTICA S.A., 1987

Figure 4 – Airplane Passenger Seat's Articulating Armrest



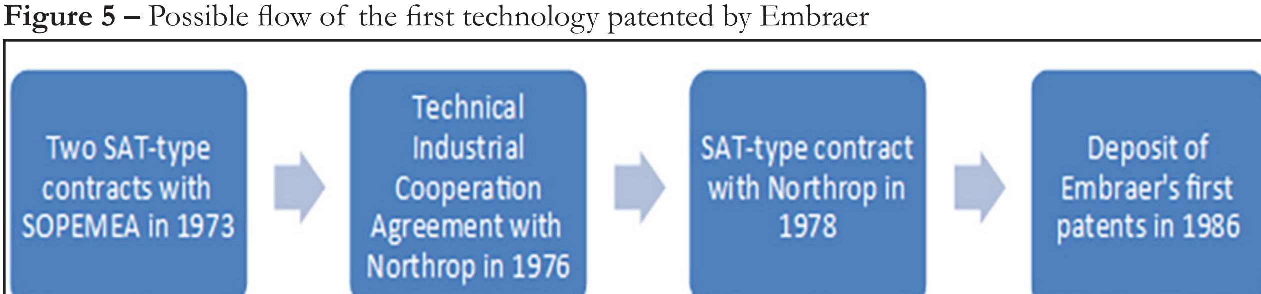
Source: EMBRAER EMPRESA BRASILEIRA DE AERONÁUTICA S.A., 1986

Based on the document descriptions, one can notice that both technologies employ carbon fiber and epoxy-based adhesive, currently known as composite materials. These data suggest that since the 1980s, Embraer has been developing expertise in the manufacturing of aeronautical components using composite materials, likely preceded by technical-assistance contracts or offset agreements that supported the in-house development of this technology.

For the historical record, up to the filing of the aforementioned patents, Embraer had registered only 4 technology transfer agreements with the INPI (possibly giving rise to the 2 filed patents). On February 16, 1973, the company signed a technical and scientific assistance contract with SOPEMEA, a French company specializing in the improvement of aerospace materials and equipment, registered under application 730587 and protocol 1058437. On April 11 of the same year, a second technical and scientific assistance contract was established with the same SOPEMEA, identified by application 731242 and protocol 1058160, possibly reinforcing the technical cooperation and expanding Embraer's technological base for the utilization of the subsequently patented materials.

It is noted that the mentioned contracts are dated a few years prior to the first patent filings, suggesting that technology transfer to Embraer occurred, which was permanently incorporated into the company and used to develop the patented items, as exemplified in the image:

Figure 5 – Possible flow of the first technology patented by Embraer



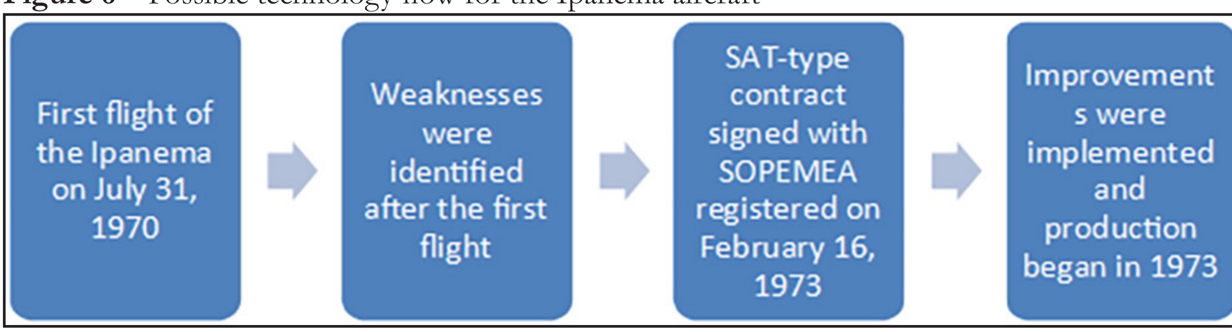
Source: author (2025).

It is understandable that the first registered technology transfer contracts date from 1973, 1976, and 1978, as even the acquisition of external technology requires a prior technological base. Thus, before these contracts, the development of technological foundations in conjunction with the CTA was essential, preparing the company to subsequently enter into its own technology transfer agreements.

This timeframe of the first registered contracts also coincides with the start of production of the agricultural aircraft EMB 200 Ipanema, which has been in continuous manufacture from 1973 to the present day, having performed its maiden flight on July 31, 1970 (Embraer S.A., 2022). It is observed that the first registered contract dates from February 16, 1973, under the SAT (Technical Assistance Service) category, signed with SOPEMEA, suggesting a possible relationship between this agreement and the development of the aircraft.

It is significant that the contract date lies within the interval between the Ipanema's first flight and the start of its production, which occurred months after the agreement was registered. Thus, there is another possible technology flow:

Figure 6 – Possible technology flow for the Ipanema aircraft



Source: author (2025).

The same pattern may have occurred in the manufacturing of the EMB 110 Bandeirante, which performed its maiden flight on August 16, 1972, and was produced from 1975 to 1991 (Embraer S.A., 2022).

These contracts registered in the 1970s may indicate the beginning of Embraer's technological autonomy from the CTA, considering the substantial increase in technological agreements with foreign institutions during this period, according to INPI data.

The technology transfer agreements registered up to 1978 were apparently part of the process that resulted in Embraer's first two patents, representing an advance in the consolidation of aeronautical manufacturing technology following the initial projects developed with the CTA.

Indeed, the flow of technology imported by Embraer for aircraft development and production intensified significantly through the licensing of aeronautical construction designs, as shown in the table below, which enabled the absorption and development of expertise for aircraft production.

Tabela 1 – Aircraft manufactured by Embraer under license until the year 2000

AIRCRAFT	ENGINE	FIRST FLIGHT	PRODUCTION	PROJECT
EMB 326 Xavante	Turbojato	03/09/1971	1971 to 1981 (in Brazil)	Aermacchi, produced under license by Embraer
EMB 710 Carioca	Piston	1975	1975 to 1983	Piper Aircraft, produced under license by Embraer
EMB 711 Corisco	Piston	1975	1975 to 1990	Piper Aircraft, produced under license by Embraer
EMB 711ST Corisco Turbo	Turbo Piston	1980	1980 to 2000	Piper Aircraft, produced under license by Embraer
EMB 720 Minuano (A/B)	Piston	1975	1975 to 1996	Piper Aircraft, produced under license by Embraer
EMB 721 Sertanejo (A/B)	Piston	1976	1976 to 2000	Piper Aircraft, produced under license by Embraer
EMB 810 Seneca	Piston	1975	1975 to 2000	Piper Aircraft, produced under license by Embraer
EMB 820 Navajo	Piston	December 1975	1975 to 2000	Piper Aircraft, produced under license by Embraer
EMB 712 Tupi	Piston	1979	1979 to 1990	Piper Aircraft, produced under license by Embraer
N 821 Carajá	Turboprop	-	1984 to 1992	Manufactured in partnership with Piper Aircraft
AMX (Militar)	Turbofan	16/10/1985	1986 to 1999	Manufactured in partnership with Aermacchi

Source: EMBRAER S.A., 2022

The data in the table describe various aircraft produced or assembled by Embraer under license until 2000, all in partnership with foreign companies, bringing aeronautical production, management, and integration techniques to Brazil. In the same period (mid-1970s to the early 2000s), only four aircraft were fully developed and manufactured by Embraer: EMB 312 Tucano, EMB 121 Xingu, EMB 111 Bandeirante Patrulha, and EMB 110 Bandeirante.

This duality between licensed production and in-house development reflects the company's strategy of combining foreign technological absorption with the construction of local competencies and the consolidation of imported technologies. While international partnerships provided technical and managerial knowledge, national projects demonstrated the company's capacity for innovation and growing technological autonomy.

It is noted that the majority of the aircraft in the table were produced under license from Piper Aircraft. Embraer acted mainly as a manufacturer of other companies' designs during varying periods. The EMB 326 Xavante and the AMX were developed in partnership with Aermacchi, while the N 821 Carajá was manufactured with Piper Aircraft, differing in the use of a turboprop engine instead of a piston engine.

Still in the period from the mid-1970s to the early 2000s, a significant increase was observed in contracts registered with the INPI with Embraer as the assignee (*cessionária*). Several international companies established agreements with Embraer, covering patent exploitation, technology supply, technical-industrial cooperation, and technical and scientific assistance services.

Among Embraer's main international partnerships during this period, the following stand out:

ALKAN (France) established two agreements on May 29, 1987: patent exploitation (Application 871089) and technology supply (Application 871088).

MAGNAGHI OLEODINAMICA (Italy) signed two technology supply agreements on July 9, 1992 (Applications 921851 and 921852). On the same date, TACTAIR FLUID CONTROLS (USA) executed two similar agreements (Applications 921853 and 921854).

BRITISH AEROSPACE (United Kingdom) established a technical and scientific assistance contract on December 30, 1993 (Application 931429).

In 1999, technical and scientific assistance contracts were signed by: SONACA (Belgium) and GENERAL ELECTRIC (USA) on September 14; KAWASAKI HEAVY INDUSTRIES (Japan) on September 29; and ELBIT SYSTEMS (Israel) on October 8.

LMS INTERNATIONAL (Belgium) executed two assistance agreements on October 28, 1999, and March 24, 2000.

Finally, among the most relevant contractors, BOEING TECHNOLOGY SERVICES (USA) executed four technical and scientific assistance service agreements: one on May 23, 2000 (Application No. 000545, Protocol 10894), another on June 28, 2000 (Application No. 000650, Protocol 11111), one on July 4, 2000 (Application No. 000688, Protocol 11174), and one on December 15, 2000 (Application No. 001287, Protocol 12190).

An expressive growth is observed in the quantity of contracts registered with the INPI from the 1970s to the early 2000s, indicating significant investment in technology importation. This process occurred independently of the IP legislation in force in Brazil and worldwide, as the old Industrial Property Code and the PCT were still in effect until 1996, while the TRIPS Agreement and the current Industrial Property Law only entered into force in 1994 and 1997, respectively, at the end of the analyzed period.

These historical precedents evidence the importance of intellectual property and technology transfer as catalysts for development in the aeronautical industry, highlighting Embraer's capacity to effectively absorb technologies obtained through contracts and strategic partnerships.

The partnership with foreign companies provided Embraer with technical knowledge and experience in aircraft design, manufacturing, and operation. This technology transfer allowed for the adaptation and improvement of internal processes, enabling the company to develop globally competitive aircraft.

International collaboration went beyond technical knowledge, also including the import of advanced technologies, as exemplified by the patent exploitation agreement with ALKAN

- STE R. ALKAN & CIE EQUIPEMENTS AERONAUTIQUES, signed on May 29, 1987.

These foreign collaborations and technological transfers provoked a significant transformation in Embraer's business model, which migrated from licensed production to the development of proprietary aircraft, a shift evidenced in the aircraft that entered production starting in 2001, as shown in the following table.Source: EMBRAER S.A., 2022

Tabela 2 –Aircraft Developed by Embraer

AIRCRAFT	ENGINE	FIRST FLIGHT	PRODUCTION	PROJECT
EMB 200 Ipanema	Piston	31/07/1970	1973 to present	Embraer proprietary development
EMB 120 Brasília	Turboprop	25/07/1983	1983 to 2001	Embraer proprietary development
ERJ 145	Turbofan	11/08/1995	1995 to present	Embraer proprietary development
ERJ 135	Turbofan	04/07/1998	1999 to 2011	Embraer proprietary development
ERJ 140	Turbofan	27/06/2000	2001 to 2011	Embraer proprietary development
ERJ 145XR	Turbofan	02/06/2001	1995 to present	Embraer proprietary development
EMB 145 AEW&C (E-99 / R-99A), RS/AGS (R-99B) e MP/ASW (P-99)	Turbofan	22/05/1999	2001 to present	Embraer proprietary development
EMB 314 Super Tucano	Turboprop	02/06/1999	2003 to present	Embraer proprietary development
Legacy 600	Turbofan	31/03/2001	2002 to present	Embraer proprietary development
E170	Turbofan	19/02/2002	2002 to present	Embraer proprietary development
E175	Turbofan	14/06/2003	2004 to present	Embraer proprietary development
E190	Turbofan	12/03/2004	2004 to present	Embraer proprietary development
E195	Turbofan	07/12/2004	2006 to present	Embraer proprietary development
Lineage 1000 / 1000E	Turbofan	26/10/2007	-	Embraer proprietary development
Phenom 100 / 100EV	Turbofan	26/07/2007	2008 to present	Embraer proprietary development
Phenom 300 / 300E	Turbofan	29/04/2008	2009 to present	Embraer proprietary development

Legacy 650	Turbofan	-	-	Embraer proprietary development
Legacy 500	Turbofan	27/11/2012	-	Embraer proprietary development
Legacy 450	Turbofan	28/12/2013	-	Embraer proprietary development
KC-390 Millennium	Turbofan	03/02/2015	starting in 2018	Embraer proprietary development
E190-E2	Turbofan	23/05/2016	-	Embraer proprietary development
E195-E2	Turbofan	29/03/2019	started in 2019	Embraer proprietary development
Praetor 600	Turbofan	-	-	Embraer proprietary development
Praetor 500	Turbofan	-	-	Embraer proprietary development
eVTOL	Electric	-	-	Embraer - EVE development

Source: EMBRAER S.A., 2022

The table reveals Embraer's evolution in developing proprietary aircraft and those developed through partnerships. Beginning with the EMB 200 Ipanema in 1970 (an agricultural aircraft that remains in production), followed by the EMB 120 Brasilia in 1983 and the ERJ regional jet family.

In 1999, the company launched the EMB 314 Super Tucano for military use, subsequently expanding into executive jets with the Legacy line (2001-2013). In the commercial sector, it developed the E-Jet family starting in 2002, including the recent E190-E2 and E195-E2 models.

For the military sector, it produced the KC-390 Millennium (2018) , while diversifying its executive line with the Lineage 1000/1000E, Phenom 100/100EV, Phenom 300/300E, and Praetor 600 and 500. Currently, Embraer is exploring futuristic technologies with electric eVTOLs through its EVE division.

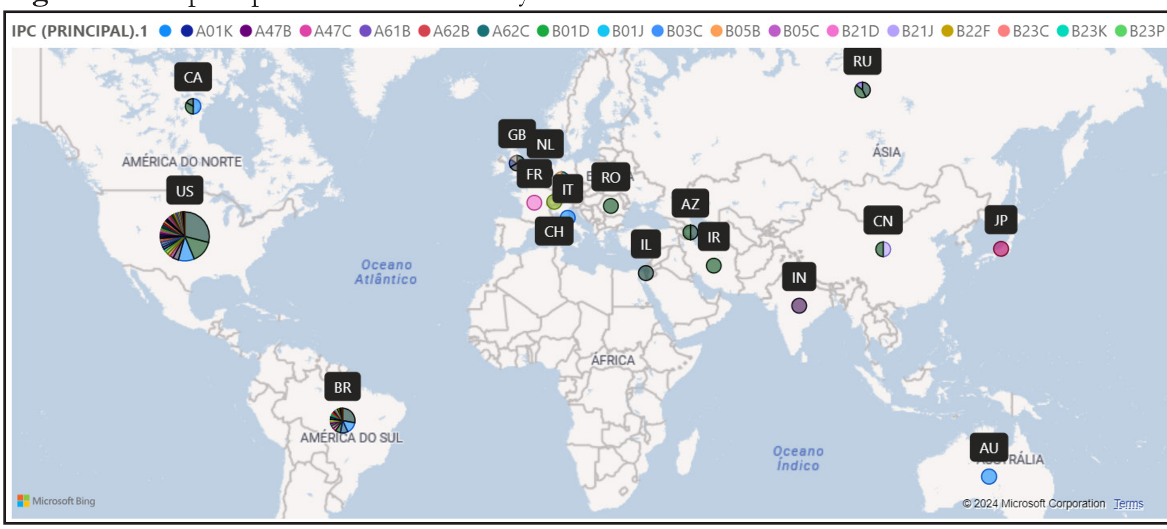
The company's trajectory demonstrates a clear evolution: initially relying on strategic partners for technological development, it later directed efforts toward proprietary projects. This shift transformed its contractual approach, migrating from the acquisition of ready-made technologies to partnerships focused on specific developments and specialized testing for its proprietary projects.

3.4 Period 2000-2020

The year 2000 represents the inflection point in Embraer's technological and market strategy, when the company redirected its focus from the production of licensed designs to the development of proprietary aircraft. This milestone evidences its technological maturity, allowing it to resort to TT only to solve specific problems or develop targeted technologies, abandoning the importation of complete solutions. This strategic transformation indicates its maturation as an innovative company and reflects its technological evolution, driven by incremental innovations. Greater investment in R&D enabled the search for customized solutions aligned with its specific needs, strengthening its global competitive position.

This shift in approach is clearly demonstrated by the company's patent filing profile, which assumed a more proactive stance in the development and protection of its inventions with a significant increase in the number of filings. These patents cover various areas, including aircraft design, propulsion systems, avionics, and construction materials, and are distributed across several countries, as illustrated in the mentioned map (Figure 7), where the circle sizes represent the quantity of patents per country and the colors indicate the technological areas according to the WIPO IPC classification.

Figura 7 – Map of patent families filed by Embraer



Source: author, 2025.

This vast intellectual property portfolio positions Embraer as a leader in the civil aviation sector and demonstrates its investment in research and development to drive competitiveness and technological excellence.

4 FINAL CONSIDERATIONS

The analysis conducted in this article demonstrates that, since its inception, aviation has evolved from empirical observations to a discipline based on rigorous scientific principles, which allowed for the development of technically viable aircraft. Without science and technology, this industry would not have reached its current technological level, remaining at the forefront of innovation across several fields. The sector's development was significant in the first half of the 20th century, accelerating in the post-World War II period.

In this context, Brazil's entry into this sector was late, which demanded concerted efforts from the country in the development of competencies and qualified personnel. Thus, technology transfer was a fundamental pillar. Through local and international partnerships, technical and organizational knowledge was absorbed, enabling the development of proprietary projects and global competition.

The trajectory of the sector in Brazil, especially from the 1970s onwards, is intertwined with the history of Embraer, which illustrates how a company can evolve from dependence on foreign technologies to global leadership. The combination of technology transfer, investment in R&D, and innovation was essential in this process. The company transitioned from licensed production to the creation of competitive aircraft, such as the E-Jets family, highlighting the importance of a continuous innovation strategy.

Furthermore, through intellectual property (IP) instruments, such as patents and know-how, it was ensured that investments for the development of inventions were rewarded, while the evolution of national and international IP legislation created an even more secure environment for this development.

From the 2000s onwards, Embraer focused on the development of proprietary projects, reducing reliance on foreign technologies. This shift reflected technological maturation, with greater investment in R&D and a significant increase in the number of filed patents. However, the aeronautical industry faces new challenges, and the capacity for adaptation and innovation will be decisive in maintaining global competitiveness.

Finally, Embraer has not only consolidated itself as a global leader but has also contributed to Brazil's economic and technological development. Its trajectory serves as a model for other high-tech industries, highlighting the importance of innovation, technology transfer, and collaboration between public and private sectors. The intersection of science, technology, and innovation reveals a dynamic and continuous process, driven by the human quest to overcome limits and explore new frontiers.

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Contribuições dos autores:

O autor Bruno Rabelo Coutinho Saraiva foi responsável pela conceituação do estudo, curadoria dos dados e análise formal, além de conduzir a investigação e atuar na redação, revisão e edição do manuscrito. O autor Francisco Fábio Cavalcante Barros contribuiu com a supervisão e validação da pesquisa, além do fornecimento de recursos e materiais de estudo essenciais. Já a autora Tecia Vieira Carvalho atuou na aquisição de financiamento, fornecimento de recursos e validação dos resultados, participando ativamente da redação, revisão e edição do trabalho.

Como citar este artigo:

ABNT

SARAIVA, B. R. C; BARROS, F. F. C.; CARVALHO, T. V. Science, technology and innovation in the brazilian aeronautical industry: a study of Embraer´s trajectory in technology transfer and patent development. **Revista da UNIFA**, Rio de Janeiro, v. 39, p. 1-28, 2026.

APA

SARAIVA, B. R. C; BARROS, F. F. C.; CARVALHO, T. V. (maio, 2026) Science, technology and innovation in the brazilian aeronautical industry: a study of Embraer´s trajectory in technology transfer and patent development. **Revista da UNIFA**, 39 (1), P. 1-28.

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Disclosure statement

The authors report there are no competing interests to declare.

Funding details

This work was supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

Recebido: 14 jan 2026

Aceito: 20 abr 2026