RADAR TECNOLÓGICO INPI

Mapping of artificial intelligence technologies applied to aeronautics, in Brazil and Sweden, through an assessment of patents related to this industry

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Artificial Intelligence in the Aeronautical Industry

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Abbreviations

ATC – Air Traffic Control

CNAE – National Classification of Economic Activities

CPC – Cooperative Patent Classification

DAI – Distributed Artificial Intelligence

ECAM – Electronic Centralized Aircraft Monitor

EICAS – Engine Indicating and Crew Alerting System

EP – European Patent

EPC – European Patent Convention

EPO – European Patent Office

EUA – United States of America

F-terms – File Forming Term

FI – File Index

FURB – Regional University Foundation of Blumenau

HLG – Brazil-Sweden High-Level Group on Aeronautics

HMI – Human machine interface

IA – Artificial Intelligence

IBGE – Brazilian Institute of Geography and Statistics

INPI – Brazilian National Institute of Industrial Property

IPC – International Patent Classification

IoT – Internet of Things

IoTA – IoT applied to the aerospace system

KRR – Knowledge Representation and Reasoning

NLP – Natural Language Processing

OMPI – World Intellectual Property Organization

P, D & I – Research, Development, and Innovation

PI – Intellectual Property

GDP – Gross Domestic Product

PF – Individual (Inventors)

PRV – Swedish Intellectual Property Office

TIC – Information and Communication Technology

UCS – University of Caxias do Sul

UFMG – Federal University of Minas Gerais

USP – University of São Paulo

UAV – Unmanned Aerial Vehicle

VTOL – Vertical Take-Off and Landing

1 Introduction

This study was carried out in the scope of the Brazil-Sweden High-Level Group on Aeronautics – HLG, a partnership involving governments, industry, and academia from both countries, aiming at cooperation for technological development in the sector. INPI is part of the executive committee of HLG since 2020 and has proposed to carry out a technological mapping through surveys of patent documents in areas of interest to HLG, considering the applications filed in these two countries.

1.1 Brazil-Sweden High-Level Group on Aeronautics (HLG)

The HLG was established during the meeting of the Joint Committee on Economic, Trade, and Technological Cooperation held on May 21, 2015. The Group is coordinated by the Executive Secretary of the former Ministry of Development Industry, and Foreign Trade – MDIC (current Ministry of Economy) and the secretary of state of the Swedish Ministry of Enterprise and Innovation.

The creation of HLG can be considered a consequence of the Brazilian government's purchase of 36 Swedish fighter planes. One of the main reasons for choosing the Swedish company when compared to the other competitors was the technology transfer and the possibility of inserting Brazilian companies into Saab's global supply chain by manufacturing some components of the Gripen NG fighter, providing Brazil with access to new markets.[1]

The first meeting of HLG was held on October 19, 2015. In 2020, INPI was invited to join the Executive Committee of HLG – EC-HLG, which occurred in October of this same year. One of the activities proposed to INPI in the scope of HLG was to present a technological mapping study through a survey of patent

[1] https://www.gov.br/produtividade-e-comercio-exterior/pt-br/assuntos/noticias/mdic/competitividade-industrial/gan-brasil-suecia-em-aeronautica

documents in areas of interest to HLG, Artificial Intelligence being one of the areas pointed out by the group.

1.2 The Aeronautical Industry and the patent system

The aeronautical industry is a sector encompassing government or private companies, whose activity is the research, development, manufacturing, service, and commercialization of aircraft (airplanes or helicopters) and their components (avionics). The products of this sector are characterized by a high technological content, as well as high added value. The aeronautical industry is part of a larger sector, the aerospace industry, which also involves the development of technologies related to rockets, satellites, etc.

Aeronautical Sciences is a highly strategic technological area for both Brazil and Sweden. While Brazil is one of the four largest civil aircraft manufacturers in the world, Sweden, on the other hand, is an important manufacturer of military aircraft as well as a supplier of components and technology for civil aircraft assemblies. Additionally, it is important to highlight that the aeronautical Industry strongly depends on advanced technologies, with strong indirect effects extended not only to its core technologies, but also to a whole range of technologies, with cross-sectional characteristics, extending far beyond the aeronautical area, such as, for example, the automotive industry, TIC, and many others.[2]

Patents are important and strategic tools within the aerospace industry and can be used to block competitors, ensure market freedoms, and facilitate business and research partnerships. Through the patent system, inventors can ensure market exclusivity for their innovations for up to twenty years, creating a lasting competitive advantage. Moreover, patents can

[2] https://www.cisb.org.br/images/pdf/Folder%20-%20Cooperation%20Brazil-Sweden%20in%20Aeronautics%20and%20Defence.pdf?msclkid=766f462db9b911ecbc66e7d0026a5801

be used by governments and decision makers as indicators of innovation and success in the industry.

The role of patents in aviation history reveals three important stages of development: the first years of open collaboration, followed by the emergence of a new industry, and finally the war years. Each of these stages provided a different innovation scenario and dynamic among inventors, academic institutions, governments, and the economic environment. Hamdan-Livramento (2018) expatiates the decisive role that governments had in the development of aircraft, particularly during the two world wars, as aircraft were deemed to be strategic weapons, so their development quickly became a priority. However, as airplanes became more complex, the industry's innovation ecosystem has also evolved. Supply chains have become increasingly complex, requiring more focus on coordinating the integration of many different technologies optimally and economically, involving close collaboration with a series of technology suppliers.

Historically, aerospace organizations tended to protect Intellectual Property (IP) through trade secrets, know-how, and trade agreement. This has been changing in the last decades as international aerospace patents have seen an increasing growth rate. National policies, corporate incentives, new technologies, and maturing markets were the major drivers of this change.[3]

Also in Brazil, for some time, the issue of the appropriation of Industrial Property rights or the use of Industrial Secrets was discussed in the aeronautical industry, mainly due to the development of military applications. Today, however, it is increasingly agreed that military demands occur seasonally and that dual use is important to maintain the economic flow of these companies, with growth in patent filings to the detriment of maintaining the technology in Industrial Secrecy.

[3] https://www.ati.org.uk/wp-content/uploads/2021/08/insight_11-global-aerospace-patents-1.pdf

It is important to consider that the patent system has slight nuances in the different countries, and applicants can consider different patenting routes and strategies according to the markets of interest and the national or regional laws and regulations, which may reflect in the number of documents identified in each office.

For European countries, applicants can file directly with national offices or the European Patent Office – EPO. European patents are granted through a centralized examination procedure at EPO and are therefore faster and more economical than filing a patent application in each country where the invention is to be protected. Considering that there are 38 EPO contracting states (including Sweden), it makes sense to file a European patent application instead of national applications when protection is sought in at least four European countries. The European patent is usually granted within 3 to 4 years after filing. However, the European procedure has not replaced national grant procedures, so once the grant is published, the European patent shall be validated in each of the designated states within a specific time frame to maintain its protective effect. Validation requirements may differ by country.[4]

Specifically, in the case of Sweden, a translation of the claims into Swedish or English shall be provided under the conditions provided for in Art. 65(1) EPC.[5] The Swedish Patent is then published with the kind code T3 by the Swedish Intellectual Property Office – PRV, which corresponds to the publication of the translation of the EP patent.

Some studies discuss the role of Intellectual Property, patents, and innovation in the Aeronautical industry (Mccarville, 2012), or present mappings of patents in the aerospace industry over the last few years, such as the Aerospace Technology Institute report (2019) which discusses technological maturity

[4] https://www.epo.org/applying/european/Guide-for-applicants.html
[5] https://www.epo.org/law-practice/legal-texts/html/natlaw/en/iv/se.htm and https://www.prv.se/en/patents/applying-for-a-patent/international-protection/european-patent-applications/validation-of-european-patents/typical-examples-of-validation/

and new markets and technological advances as key factors for increased patent filing activity, also identifying new vertical take-off and landing (VTOL) aircraft concepts and electrification technologies as those that have become more prevalent, signaling disruptive potential of these technologies.

1.3 Artificial Intelligence (AI)

In the specific case of Artificial Intelligence (AI), it is estimated that the technology's potential impact on global Gross Domestic Product (GDP) will be in the order of USD15,7 trillion by 2030 and that 85% of customer interactions may move to be managed without humans (Organization for Economic Co-operation and Development – OECD, 2020). Applications of AI can produce radical effects on files, products, inputs, organizations, infrastructures, and markets. Even though they are technologies at different stages of development, the pace of technical progress is very intense, as is that of general application in the industry (IEL, 2018).

A recent study by the World Intellectual Property Organization (OMPI, 2019) presents a worldwide overview of patenting in AI technologies, where it was shown that many of these technologies can be used in different sectors. The transport industry stands out not only in the general results but also appears among the fields with the highest growth rates in AI patent applications, with an annual growth rate of 33% between 2013 and 2016. Within the transportation category, the aerospace/avionics (67% annual growth) and autonomous vehicles (42%) subcategories grew rapidly. The boom in transportation technologies was also evidenced by analyzing trends during the period from 2006 to 2016: accounting for only 20% of applications in 2006 and reaching one-third of applications in 2016.

A technological mapping of the Artificial Intelligence sector through patents filed in Brazil was presented in the Technological Radar published by INPI in 2020 (von der Weid & Villa verde, 2020). In this study, it was shown that, also in Brazil, the scope of application of AI with the highest number of patent application filed was Transportation, and that Boeing figured as the sixth largest applicant of AI applications in the country.

1.4 Artificial Intelligence applied to the aeronautical industry

Artificial Intelligence and cognition technologies that process and interpret a great amount of data (Big Data) are already part of many routines in aviation and are constantly being adopted in a multitude of commercial goods and services, pushing the boundaries of automation.

Since automation in aviation is already well known (such as Electronic Centralized Aircraft Monitor (ECAM)/Engine Indicating and Crew Alerting System[6] (EICAS), autopilot, etc.), we should make a distinction here between automation and artificial intelligence to understand how this technological boundary separates itself from technology already in use. While automation operates with little or no human iteration based on some specific patterns to perform repetitive tasks, AI can be defined as a collection of several different technologies that allow the machine to operate at a level of intelligence equivalent to that of a human. This process requires learning from past experiences and self-correction, allowing quick decision-making. So we can say that AI is based on non-repetitive tasks, involving learning from processing and interpreting a great amount of data, and interactions with humans.

In the Aeronautical industry, for example, AI has been applied in different domains, from operation optimization, including aircraft manufacturing, predictive maintenance, safety, user experience, and revenue management, to fully autonomous aircraft.[7] The air transport system faces several challenges for which AI can offer opportunities, such as: increasing air traffic

[6] Monitoring panels connected to diagnostic systems
[7] https://www.whatnextglobal.com/post/artificial-intelligence-in-aviation

volumes, stricter environmental standards, increasing systems complexity, and a greater focus on competitiveness.

Thus, AI can be integrated into critical systems to make aircraft increasingly independent. Equipment with these skills will learn to react to the different situations they face. As an example of this application, we have AI-based systems for managing air traffic incorporated into airports, capable of dealing with large volumes of data, understanding the context, and minimizing decision-making time.

One of the strands of AI, the Internet of Things (IoT), is a concept that refers to objects that are connected to the network. The main uses are automation and remote access, and data collection. It is with data generated by objects connected to the Internet that algorithms enable machines to learn and function autonomously. Likewise, IoT uses AI to analyze the collected data.

IoT applied to the aerospace system (IoTA) can be defined as aircraft systems with embedded computing devices that can communicate with other devices through a secure deterministic network, and thus make decisions based on “Swarm Intelligence”, functioning in a self-organized and decentralized manner. Ramaligam, et al. (2017) analyzed the potential of IoTA, identifying more than 20 relevant IoT characteristics applied in the industry, the maturity levels of these technologies, and their possible impact on the aerospace system.

Robotics is another functional application of AI that has been growing over the last few years in the aerospace, defense, and security sectors. Robots have become progressively cheaper, smarter, more flexible, and easier to train. The Airforce Technology [8] website features a dashboard of data and information about robotics in the aerospace, defense, and security sectors, including data from patent filings in the last 20 years.

[8] https://www.airforce-technology.com/robotics-in-aerospace-defence-security/

2 Objective of the Study

Considering the relevance of AI to the Aeronautical industry and INPI's participation in HLG, the objective of this technological radar is to present a mapping of the application of AI in the Aeronautical industry from a portrait of patent application filings in the last 20 years, in Brazil and Sweden, to better understand the overview of technologies and players involved in the development of innovation in this industry. Considering also that Sweden is a member state of the European Patent Office – EPO, and that filing patent applications at EPO is a very common route, used mainly by large companies operating in international markets, the filing profile of patent applications at EPO, whose technological development would originate in Sweden, was also evaluated.

Thus, it was possible to (i) analyze the patenting landscape of technologies that use AI applied to the aeronautical industry in Brazil and (ii) analyze the technological development in this industry by Brazilian and Swedish applicants.

3 Methodology

3.1 AI patent applications applied to the Aeronautical industry filed in Brazil

3.1.1 Survey of AI patent applications

The first step to obtain the samples to be studied was to identify the patent applications and patents related to technologies involving Artificial Intelligence (AI) filed with the Brazilian National Institute of Industrial Property – INPI, the Swedish Intellectual Property Office – PRV, and the European Patent Office – EPO. For this survey, the methodology described in the study published by WIPO in 2019 on the topic was used. In this study, the proposed strategy uses, as search parameters for the patent documents, different technology classification codes, such as Cooperative Patent Classification (CPC), International Patent Classification (IPC), File Forming term (F-terms), and File Index (FI), as well as industry-related keywords, as shown in Annex 1. The surveys of patent applications filed in Brazil, Sweden, and EPO were carried out using the Derwent Innovation® database, since it contemplates all parameters used in the strategy proposed by WIPO, in addition to allowing the use of keywords in English, since the AI terminologies do not always have a suitable translation into Portuguese or other languages. Additionally, applications with a year of filing starting in 2000 were applied as a time restriction for the sample survey.

3.1.2 Identification of AI applications potentially applied to the Aeronautical industry

The second step was to identify, within the set of AI applications, those that would have applications in the Aeronautical industry. Based on the samples obtained from the preceding item (3.1.1), related to the documents filed in Brazil and Sweden, a verification of the classification of these patent applications containing AI techniques in the Aeronautical industry was performed. Considering the low number of applications found in the Swedish office, a complementary search of Swedish-originated applications filed with EPO was performed, considering that this may be a preferred filing route, especially for Swedish-origin applications.

Three search strategies were used for this step, namely:

(i) the IPCs and CPCs classifications that would have a direct relationship with the Aeronautical industry were identified;

(ii) keywords and phrases specific and/or related to the Aeronautical industry were defined; and

(iii) the main companies in the Aeronautical industry that could be the applicants for the patent applications were identified, be they Brazilian, Swedish, or multinational.

The lists of classifications, keywords, and companies used in the strategy can be found in Annex 2.

3.1.3 Validation of the proposed Search Strategy to identify AI patent documents applied to the Aeronautical industry

For the validation of the search strategy employed, the sample of documents filed with INPI was used. Validation of the three subsets of data generated from item 3.1.2 (classification, companies, and keywords – see Figure 1) was performed manually by reading the DWPI[9] titles and/or abstracts of the documents. Those that did not refer to the Aeronautical industry were excluded, and subsequently, the subsets were united and duplicate samples removed. Once the methodology was validated, the same procedure was carried out for the samples of applications filed in Sweden and at EPO, giving rise to the 3 samples analyzed in this technology radar – patent documents referring to AI potentially applied to aeronautics filed with INPI,

[9] Derwent Innovation provides the titles and abstracts of patent documents rewritten by experts to make it easier to identify and understand the subject matter of these patent applications.

PRV, and EPO. Figure 1 presents a schematic indicating how the obtained patent application samples were constructed, exemplified by the sample of applications filed with INPI (PRV and EPO samples were obtained using the same steps and criteria).

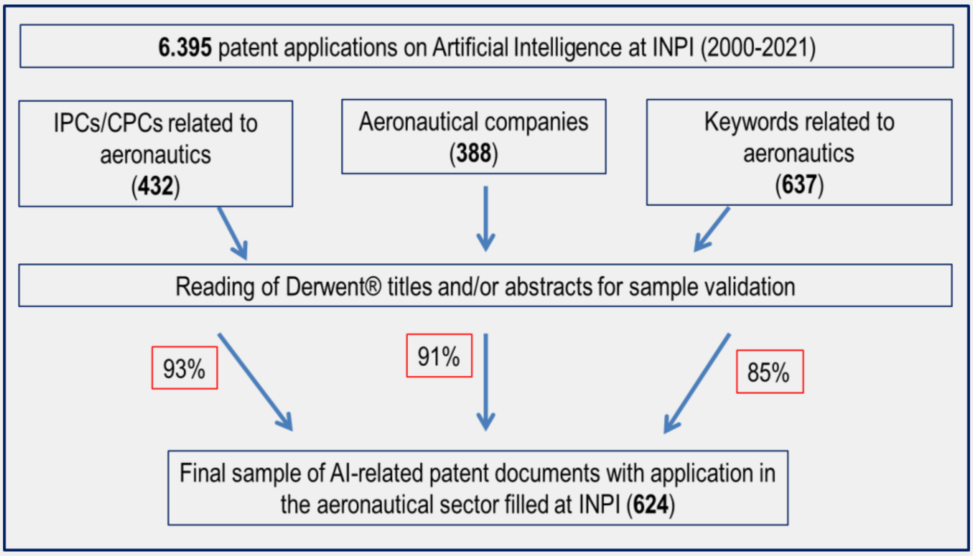

Figure 1. Scheme of the process fpr construction of the sample patent documents filed with INPI related to Artificial Intelligence potentially applied to the Aeronautical Industry

3.1.4 Categorization of patent documents according to the 3 dimensions of AI proposed by WIPO.

This categorization of patent documents is based on the scheme suggested by the WIPO study, which allows AI patents to be grouped into 3 dimensions:

"Techniques in AI", also called "core" technologies refer to advanced forms of statistical and mathematical models, enabling the calculation of tasks normally performed by humans such as machine learning, logic programming, and fuzzy logic;

"Functional Applications", which concern human functions mimicked by AI, such as speech processing or computer vision, considering that they can be realized using one or more AI techniques; and

"Application Fields", refers to different fields, areas, or courses where AI techniques or their functional applications may have applications, such as transportation, agriculture, security, medical and life sciences among others.

These three dimensions of AI can be further subdivided into several categories.

For the categorization of patent documents in these three dimensions, adaptations of the *Thesaurus* proposed in the WIPO study, which is based on Classifications (IPC and CPC) and keywords, were used (the *Thesaurus* can be found in the published WIPO study, 2019). These "dictionaries" search for keywords in the titles, abstracts, or claims of applications, as well as the classifications assigned to the same, thus relating each application to one or more AI dimensions/categories.

3.1.5 Categorization of patent applications filed in Brazil with some of the main areas of application of AI in aviation

Through reading the titles/abstracts of the 624 patent documents filed in Brazil, these were categorized according to the application areas of aviation AI to which they referred. Namely, applications were identified in the areas of (1) Aircraft Predictive Maintenance; (2) Flight efficiency optimization; (3) Virtual Pilot Assistants; (4) Manufacturing; (5) Airport services, and (6) Vertical Take-Off and Landing (VTOL).

3.1.6 Analysis of patents in the Brazilian Aeronautical industry according to the National Classification of Economic Activities (CNAE) of the companies

To know the universe of patent applications of Brazilian companies in the Aeronautical industry, regardless of whether these applications have Artificial Intelligence systems involved, we recovered from the INPI database all patent applications filed with INPI as of the year 2000, whose filing companies are classified under CNAEs 30.41-5 (Manufacture of aircraft), 30.42-3 (Manufacture of turbines, engines, and other parts and components for aircraft), and 33.16-3 (Aircraft maintenance and repair).

4 Results and Discussion

4.1 Documents related to AI applied to the Aeronautical industry in Brazil

The search of patent documents related to Artificial Intelligence filed with INPI recovered 6,395 DWPI patent families.[10] Three new searches were then performed within this set of documents according to 3.1.2 and the scheme in Figure 1. The three sets of documents were analyzed separately by reading the titles and abstracts for their relevance to the aerospace industry. Then the documents were gathered into a single set, then considered into the study sample, containing 624 patent documents related to Artificial Intelligence applied to the aerospace industry filed in Brazil between the years 2000 and 2021. Considering the initial sample of AI patent documents filed in Brazil, it was observed that about 10% of these documents potentially applied to the Aeronautical industry.

4.1.1 Validation of the search strategy

At this stage, the titles and eventually also the abstracts of the documents in each block were read in order to validate the search strategy used, and after excluding the documents considered not relevant to the industry, the 3 blocks were united and the duplicates removed. It was noted that despite the keyword search recovering a larger number of documents, it was also less assertive (85% of the sample was effectively referring to the Aeronautical industry). On the other hand, searches using patent classification (IPC/CPC) and industry applicants revealed 93 and 91% matching in the Aeronautical industry, respectively.

[10] Patent family: A patent family is the collection of patent documents relating to the same or correlated inventions, published in different countries. Each patent document in the family is usually based on data from the first application, filed in the country of priority. Each record in the Derwent World Patents Index® (DWPI) database represents a family of patent documents.

Regarding the documents recovered through the use of IPC/CPC classifications selected for the aerospace industry, it was observed that at least 93% of the documents referred to the technological sector studied, with only those documents that referred specifically to land, water, or underwater vehicles, satellites for image mapping, and elevators having been removed. Documents related to balloons were kept in the sample when they are used for monitoring, positioning, and data network platform.

Regarding applications from companies related to the aviation industry, 388 documents were recovered using the name of the applicant (Figure 1). After reading the titles/abstracts, 9% of the documents were excluded from the sample, being mainly General Electric – GE documents related to wind turbines, when the potential application in the aviation industry was not mentioned, for example, documents related to “wind farms” (general wind turbine sensor/controller systems were kept in the sample), deterioration detection systems in oil and gas exploration environments (when the possible application to aircraft fuel sensing has mentioned the documents were kept in the sample), documents of medical diagnostic methods.

We kept in the sample the documents from companies related to the aircraft construction or space industry, but which were not specific to the Aeronautical industry, such as, for example, additive manufacturing systems, and monitoring of assembly lines, sensors, and monitoring/navigation systems for vehicles in general, and image capture systems, as most of them mentioned a potential application to the aerospace industry. Among the companies with a large number of documents with a broader scope are Boeing and automotive companies such as Nissan.

The group of documents recovered from keywords or expressions related to the studied industry was the one that generated the largest number of documents. However, it was also where there was the most “noise” in the search, as 15% of the documents were not directly related to the industry of interest.

Among the words that brought the most noise to the sample were "simulator", "HMI (or human machine interface)", "flying", and "flight" (see the words used in Annex 2).

Thus, the final sample of AI documents with aerospace applications contains 624 documents that were analyzed and discussed below.

4.1.2 Overview of applications filed in Brazil

As shown in the methodology, patent applications with filing dates between the years 2000 and 2021 were analyzed. Figure 2 presents the analysis of the growth in the number of patent applications in the industry. Data from applications filed in the years 2020/2021 were not included in the figure since, due to the nondisclosure period given by the patent system (18 months until it is published unless early publication is requested by the applicant), the applications filed in recent years in the vast majority could not be recovered in the search, possibly giving a false impression of a drop in the number of filings.

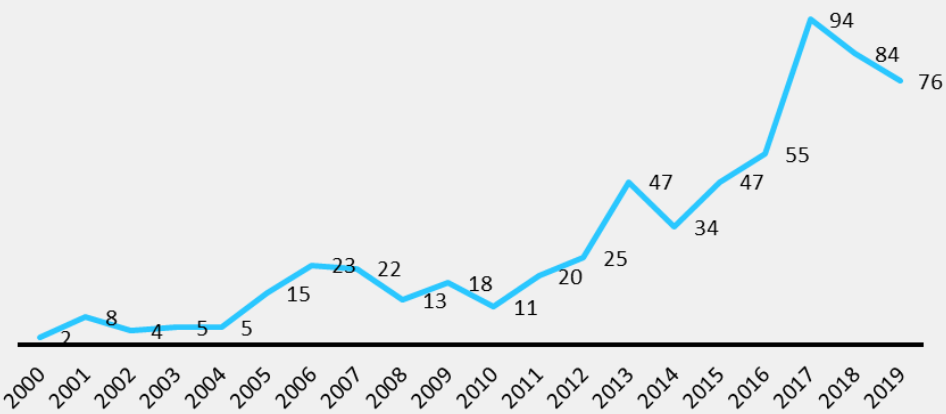

FIGURE 2. DISTRIBUTION OF AI PATENT APPLICATIONS APPLIED TO THE AERONAUTICAL INDUSTRY ACCORDING TO THE YEAR IN WHICH THESE APPLICATIONS WERE FILED

The first big climb in the number of AI patent filings in the world occurs in 2011, with patenting of technologies involving “deep learning” techniques growing exponentially from 2013, hitting 175% between 2013-2016.[11] Therefore, the spike in filings observed in Brazil as of 2013 monitors the patenting data in the world for AI technologies over the same period.

Figure 3 shows the applicants with more than 10 AI patent applications applied to the Aeronautical industry filed with INPI. Data presented are those from the national database.

The largest applicant is Boeing, with 131 patent applications, which is about 20% of the total sample. The second position among the largest applicants is shared by the French Airbus group and GE Aviation Systems, with 40 patent applications each. It is worth mentioning that subsidiaries of companies located in different countries were not considered to be the same applicant. The only national applicant to appear in the list of the largest applicants in the industry is Embraer, with 16 patent documents involving artificial intelligence applied to the Aeronautical industry, occupying the fifth position in the ranking of largest applicants.

[11] https://www.wipo.int/tech_trends/en/artificial_intelligence/story.html

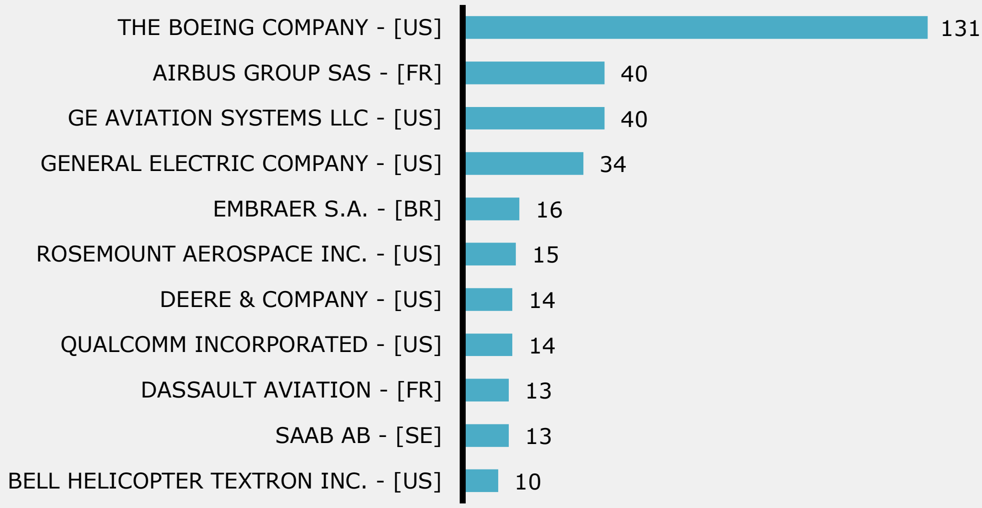

FIGURE 3. NUMBER OF PATENT APPLICATIONS FILED WITH INPI BY THE LARGEST APPLICANTS OF AI TECHNOLOGIES APPLIED TO THE AERONAUTICAL INDUSTRY

To know the origin of the technologies seeking patent protection in Brazil, the analysis of the applicants' country profile was performed, according to data obtained from the INPI database, which is presented in Figure 4, where it can be seen that about 57% of the applications in the sample are from applicants from the United States of America (USA), followed by applications from French applicants and national applicants, with 87 and 38 patent documents filed, respectively. Sweden ranks 7th with 18 documents, behind Germany, Great Britain, and Japan.

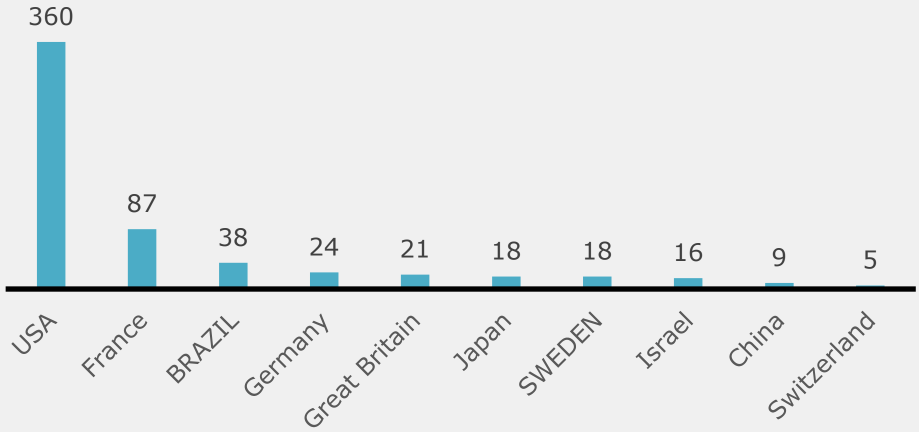

FIGURE 4. DISTRIBUTION OF AI PATENT APPLICATIONS APPLIED TO THE AERONAUTICAL INDUSTRY ACCORDING TO THE COUNTRY OF THE APPLICANTS.

To identify the main players and technologies developed by the resident applicants, a clipping of the sample was carried out. Among the 38 patent documents of national origin (see Figure 4), 23 belong to resident companies, 16 of which were filed by Embraer and another 7 applications filed by the companies Adroit Robotics Sistemas Inteligentes LTDA., Gol Linhas Aéreas S.A, NCB Sistemas Embarcados Eireli EPP, Perfect Flight Assessoria e Controle de pulverização LTDA., Perkons S.A., Skydrones Tecnologia Aviônica LTDA., and Sigma Instrumentos LTDA. (in a partnership with UFMG). Only one application was identified for each of these companies. Among Embraer's applications, 3 are in partnership with Empresa Paulista Yaborã Indústria Aeronáutica S.A and 2 are in partnership with research institutes, one with USP and University of São Carlos, and the other with SENAI in Bahia.

Five applications are from universities or research institutes: two of them in a partnership with Embraer; one application from UFMG in a partnership with Sigma Instrumentos LTDA. (as discussed above); one application whose applicant is from the University of Caxias do Sul (UCS); and one partnership of the Regional University of Blumenau Foundation (FURB) with the Federal Institute of Education, Science, and Technology of Santa Catarina. Additionally, we identified that thirteen patent applications belong to individuals (inventors), and one of the applicants has 3 applications (all related to sensors for drones and Unmanned Aerial Vehicle – UAV). In addition to this PF applicant, Embraer and Yaborã Indústria Aeronáutica S.A (applications all co-owned by Embraer), no other resident has filed more than one patent application. The distribution of patent applications of national origin, according to the legal nature of the applicants, is presented in Figure 5.

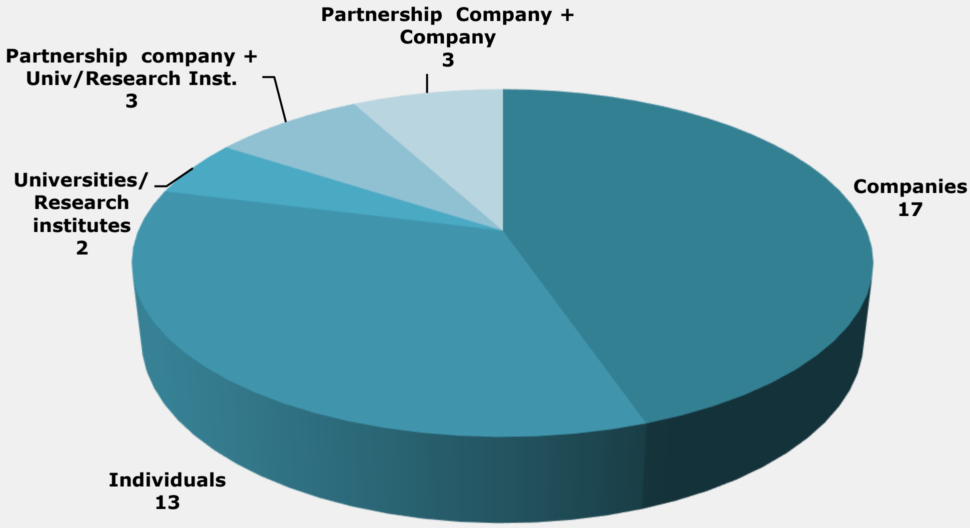

FIGURE 5. DISTRIBUTION OF AERONAUTICAL INDUSTRY PATENT APPLICATIONS CONTAINING AI TECHNOLOGY FILED WITH INPI BY RESIDENTS ACCORDING TO THE LEGAL NATURE OF THE APPLICANTS

Regarding the 18 patent applications of Swedish origin filed with INPI (see Figure 4), 13 documents were identified from Saab, 2 from Scania, 2 from Volvo, and 1 from Bae Systems.

As described in item 3.3 of the methodology, the WIPO study views AI patent documents according to what they call the 3 dimensions of AI, namely (i) **Functional applications**, (ii)

Application fields, and (iii) **AI techniques** (understood as "core" AI technologies). Thus, the applications analyzed in this study were also subjected to the categorization scheme proposed by WIPO for the 3 dimensions of AI.

Regarding the documents filled in Brazil, 99% of the sample could be fitted into the "Functional Applications" dimension proposed by WIPO. These applications were distributed into 10 categories, as shown in Figure 6. It is important to note that the same document can be assigned to more than one functional application category.

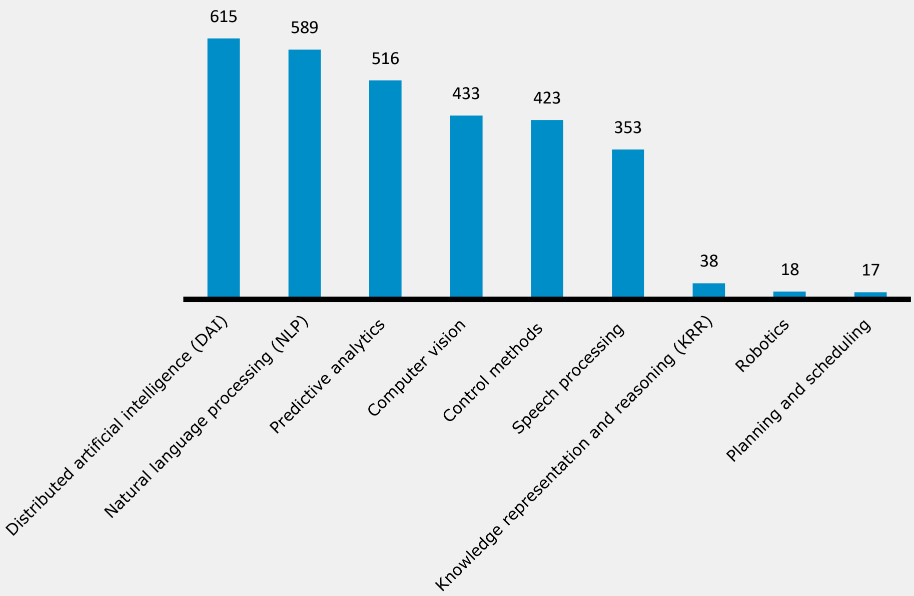

FIGURE 6. CATEGORIZATION OF THE PATENT DOCUMENTS FROM THE SAMPLE OF AI APPLICATIONS APPLIED TO THE AERONAUTICAL INDUSTRY ACCORDING TO THEIR FUNCTIONAL APPLICATIONS

Another form of categorizing the documents proposed by WIPO is according to the "Application fields" dimension of the technologies presented. As with functional applications, we can also have the same patent document assigned to more than one scope of application. Thus, 99% of the sample can also fall into this dimension. These documents have been categorized into 20 different application fields as shown in Figure 7.

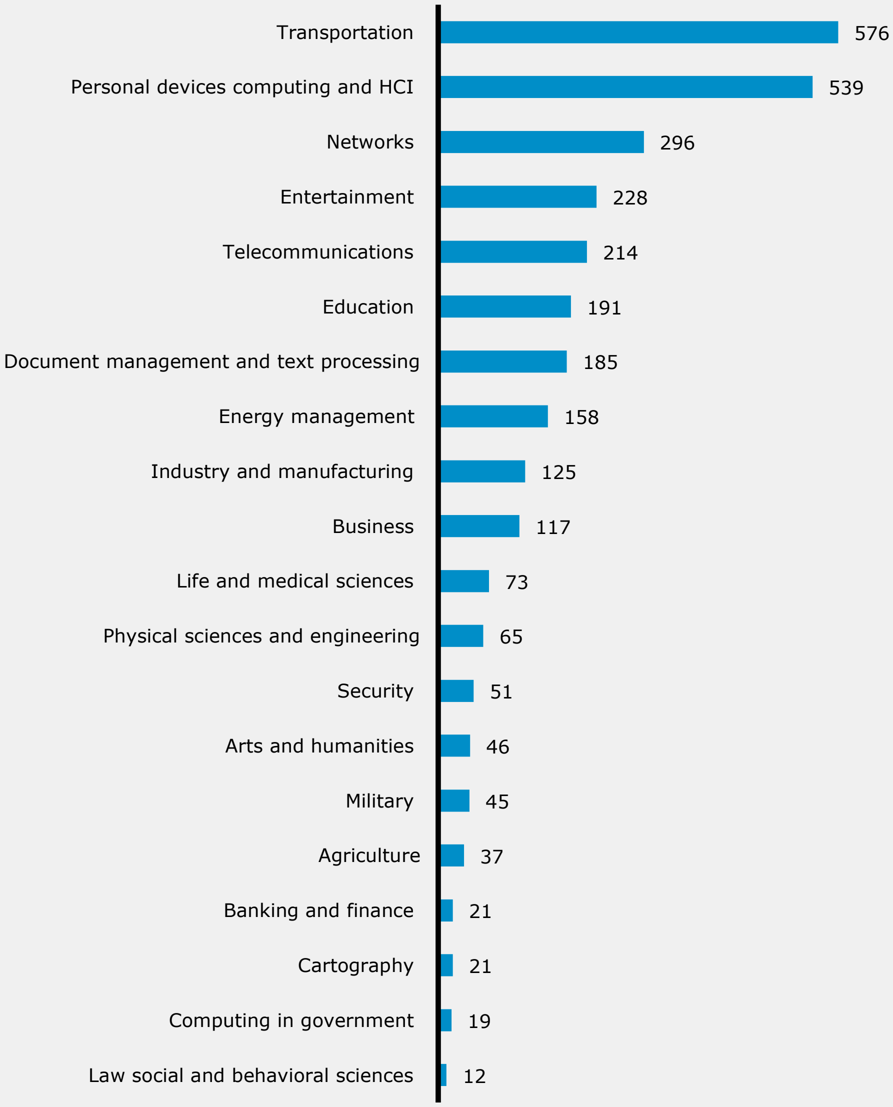

Figure 7. Categorization of the patent documents from the sample of AI applications applied to the Aeronautical industry according to their application fields

As for the documents that refer essentially to “core” technologies, only 151 documents (24%) were identified in the sample of applications filed in Brazil, using the methodology proposed by WIPO, 147 of which were identified as machine learning techniques, 5 as fuzzy logic, and 1 as Logic Programming.

Figure 8 presents the analysis of the progress of these 624 applications at INPI, having identified a little more than 1/3 still awaiting the start of technical examination, another 1/3 are applications definitively filed or patents already extinct, while 13% are granted applications/patents granted (the status of each application at the time of the study can be seen in the Excel spreadsheet in Annex 3, or by updated search on INPI website). We also identified 5 applications that used one of INPI’s priority processing programs, two of them from resident applicants (NCB Sistemas Embarcados Eireli EPP and Perfect Flight Assessoria e Controle de Pulverização LTDA).

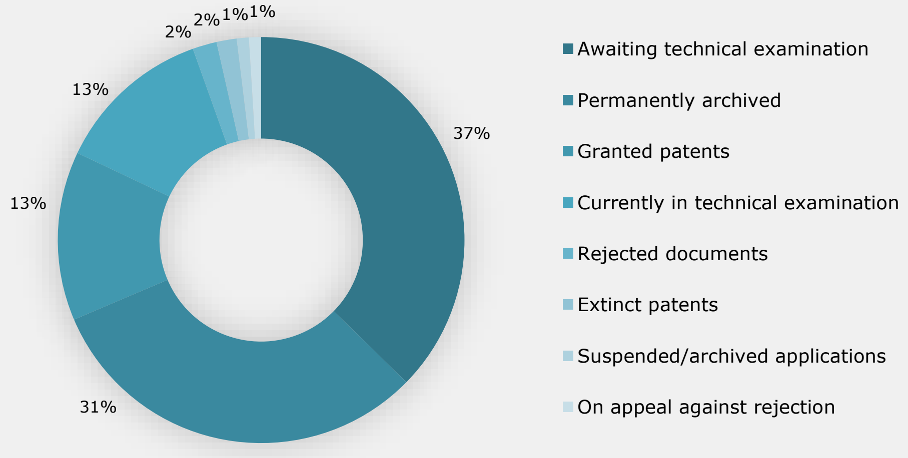

FIGURE 8. REPRESENTATION OF THE STATUS OF PATENT APPLICATIONS FILED WITH INPI RELATED TO AI AND APPLIED TO THE AERONAUTICAL INDUSTRY (IN DECEMBER 2021)

As previously discussed, Artificial Intelligence can be applied in the aviation industry in many different segments, both with equipment but also with the services provided. As an example, it is possible to mention that AI can act to facilitate analysis and optimize flight performance, optimize the maintenance of equipment, improve routes, and interact with the pilot and aircraft passengers. Thus, AI can promote benefits such as flight safety, gains in fuel consumption, and improved crew comfort. Even broader, AI can improve a series of services such as customer service, baggage management, and ticketing.

The applications filed with INPI were further categorized according to some of the main application areas of AI in aviation, as per item 3.1.5. Figure 9 shows the technologies related to "virtual pilot assistants", "VTOL", and "Flight efficiency optimization" as the ones that appear in most of the applications filed in Brazil.

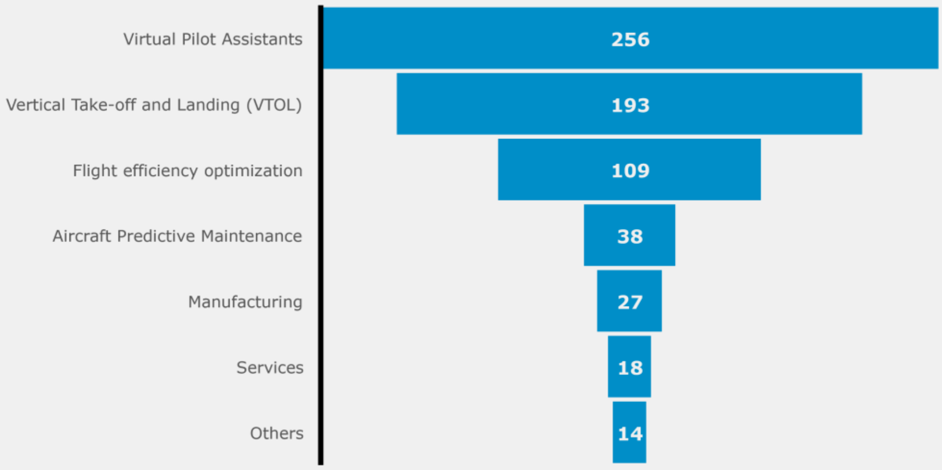

Figure 9. Categorization of the patent documents filed with INPI according to the main application areas of AI in the Aeronautical industry

The application category called "Virtual Pilot Assistants" deals with an application to improve pilot productivity and efficiency. It is a category of human interaction with AI that ranks among the most relevant, and at this category the reproduction of landscapes for visualization and the reduction of repetitive tasks such as changing radio channels, reading weather forecasts, and providing aircraft position information is particularly noteworthy. Particularly about "autonomous aircraft", the analysis of the applications found shows that Airbus, for example, has taken initiatives for such an application in taxiing, take-off and landing employing an autonomous vision system. The virtual assistant category has been extended to the cabin with the application of this concept to make passenger service and other flight attendant tasks easier and more efficient.

The category called "Vertical Take-off and Landing (VTOL)" comprises manned or unmanned vertical take-off and landing aircraft (also called drones), satellites, and rockets.

The category dealing with "Flight efficiency optimization" refers to the application of AI to optimize the aircraft's fuel utilization based on an algorithm that collects and analyzes parameters that impact flight efficiencies, such as route distance and altitude, aircraft type, weight, and meteorological conditions. These data impacts the optimization of flight efficiency so that AI allows decision-making to be done with much more support and in real-time.

The category that refers to "Aircraft Predictive Maintenance" is a relevant area of *predictive analysis*, applied to ground fleet technical support. The procedure comprises collecting extensive amounts of data in real-time, processing and storing these data on the cloud server. Maintenance occurs by hours (planned) or malfunctions/failures (unplanned) and real-time data processing can facilitate and optimize the work on the ground of the teams servicing the airlines' in-use aircraft fleet. Another area in this category would be the *analysis* of inspection *images*, for example, the wing inspection that takes place at certain flight intervals that can be seen from the cockpit, or the visual inspection of the turbine vanes/blades that takes place at pre-established time intervals.

The "Manufacturing" category refers to patent applications related to the manufacturing process of aircraft. In commercial aviation it is a process that requires long-term planning, is very expensive, and whose mistakes can have tremendous consequences. In the case of quality control, automation is applied with the help of an autonomous AI solution, in which automatic testing with the help of machine learning technologies is able to increase the defect detection rate by almost 90%. Another area of manufacturing would be "Generative Design" in which AI can be used to create parts efficiently, faster, and lighter in the aircraft industry, while applying innovative ways to design those parts.

The "Services" category encompasses everything from baggage checking with the assistance of robots and the facial recognition tool, which shall promote a lot of speed in the check-in process, to the use of recommendation machines, which analyze passengers' historical data such as past reservations, behavior tracking techniques, etc.

A correlation matrix was constructed between the 7 categories of AI application in aviation with the functional applications of AI, shown in Figure 10.

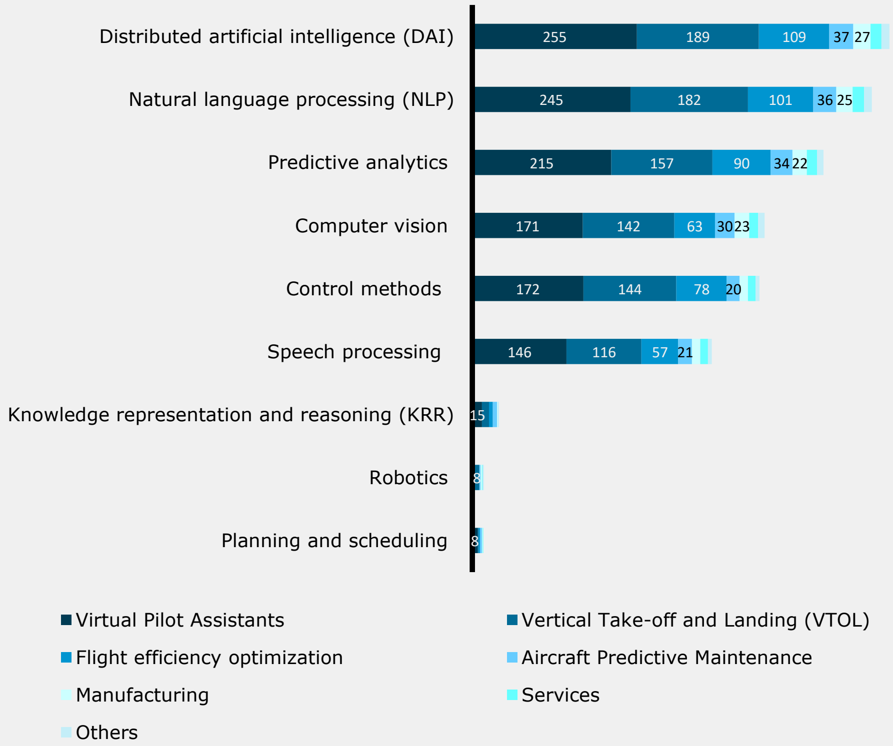

Figure 10. Correlation between AI application categories in aviation and AI functional applications

Also with respect to the categories of AI application in aircrafts, we identified which categories the applications of the main applicants in Brazil fell into. This analysis is found in Figure 11, where we observe a concentration of applications from Boeing, Airbus, and GE Aviation on applications related to virtual pilot assistants and flight efficiency optimization. We also note that all of Qualcomm's applications filed with INPI in the industry studied deal with VTOL, an area also of interest to Saab (about 70% of the applications) according to the categorization of the applications identified in the sample studied. Regarding Embraer we observe a higher concentration in applications related to virtual pilot assistants.

Total Documents		Virtual pilot assistants	Vertical Take-Off and Landing (VTOL)	Flight efficiency optimization	Aircraft predictive maintenance	Manufacturing	Airport services	Others
131	THE BOEING COMPANY - [US]	62	18	27	9	14	4	4
40	AIRBUS GROUP SAS - [FR]	28	2	13	1	1	1	
40	GE AVIATION SYSTEMS LLC - [US]	25	3	10	3	2	1	
34	GENERAL ELECTRIC COMPANY - [US]	10	2	8	4	4	2	4
16	EMBRAER S.A. - [BR]	10		6	2			
15	ROSEMOUNT AEROSPACE INC. - [US]	11		5				
14	DEERE & COMPANY - [US]	3	11					
14	QUALCOMM INCORPORATED - [US]		14					
13	DASSAULT AVIATION - [FR]	10		4	1			
13	SAAB AB - [SE]	3	9	1				
10	BELL HELICOPTER TEXTRON INC - [US]	5	2	2		2		

FIGURE 11. DISTRIBUTION OF PATENT APPLICATIONS OF THE MAIN APPLICANTS IN BRAZIL IN THE STUDIED INDUSTRY, ACCORDING TO THE APPLICATION CATEGORIES OF THESE APPLICATIONS.

Considering that only 38 patent applications were identified in the sample of applications filed in Brazil by AI residents applied to the Aeronautical industry, further analysis of the industry was made by using the National Classification of Economic Activities (CNAE) codes of the domestic applicants. This analysis aims to present the patent filing landscape by residents in the Aeronautical industry when disregarding the involvement of artificial intelligence technologies in the applications.

A total of 238 patent applications filed with INPI were identified between 2000 and 2021, whose applicants are companies classified in the CNAEs 30.41-5 (Manufacture of aircraft – 193 applications), 30.42-3 (Manufacture of turbines, engines, and other parts and components for aircraft – 214 applications), and 33.16-3 (Aircraft maintenance and repair – 208 applications). It is worth mentioning that the same company can be classified in more than one CNAE, so the sum of the numbers of applications by company CNAE category does not correspond to the total number of applications;

When we analyze the number of filings by these companies per year, it is possible to note that in the first decade analyzed (between 2000 and 2010), there was an average of 4.8 applications filed per year, while in the second decade (2011 to 2021), we note an average of 18.1 applications filed per year, an increase of almost 4 times. The vast majority of these applications are from applicants residing in the Southeast region of Brazil (mainly the state of São Paulo), followed by the South and Midwest regions, as represented in Figure 12.

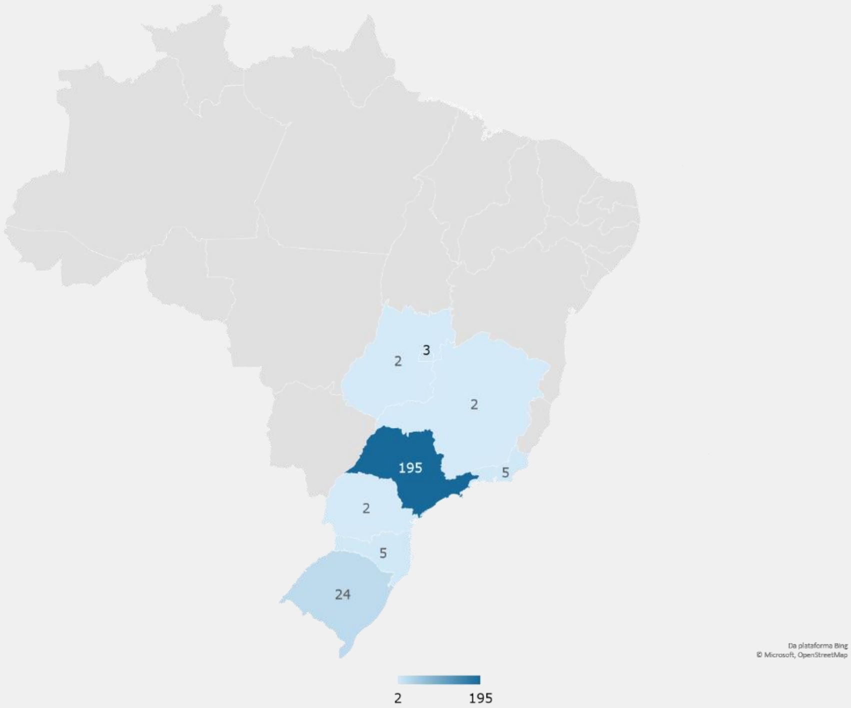

FIGURE 12. NUMBER OF PATENT APPLICATIONS FROM COMPANIES WITH AIRCRAFT-RELATED CNAE ACCORDING TO THE LOCATION OF THE APPLICANTS

When we consider the CNAEs of the resident applicants belonging to the Aeronautical Industry, the largest patent applicant in the industry is undoubtedly Embraer, as shown in Figure 13, with 155 patent applications filed between 2000-2021. As seen in Figure 3, only 16 of these requests (about 10%)

correspond to requests whose technologies are related to the use of Artificial Intelligence.

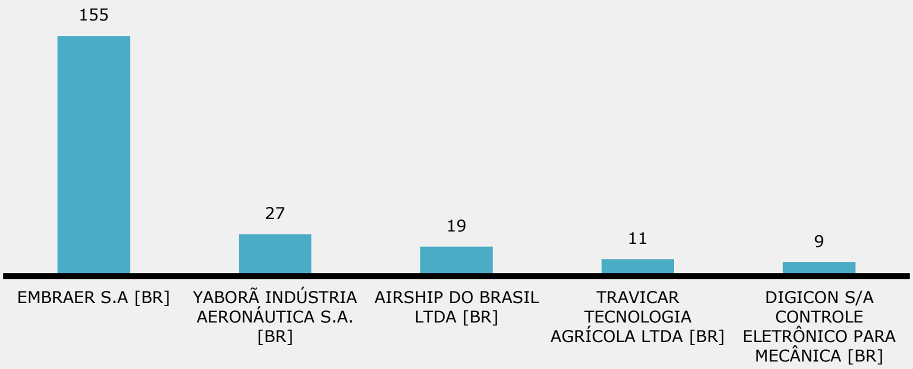

FIGURE 13. MAIN RESIDENT APPLICANTS IN THE AERONAUTICAL INDUSTRY CONSIDER THE CNAE OF THE COMPANIES, REGARDLESS OF WHETHER THE APPLICATIONS ARE RELATED TO TECHNOLOGIES INVOLVING AI

4.2 Documents related to AI applied to the Aeronautical industry filed in Sweden

The same document recovery methodology used to define the sample of AI patent documents filed in Brazil was applied to the applications filed in Sweden. Thus, 988 patent documents filed in Sweden between the years 2000-2021 related to AI were recovered. When using the methodology to identify the applications within this sample that would be related to the Aeronautical industry (see item 3.1.3 of the methodology), applying the classification, keyword, and company *Thesaurus*, a sample of only 63 documents was obtained that would be related to AI with aviation application. Of these, 62 had Swedish priority and only 1 document had foreign (US) priority. A possible explanation for this low number would be the access that Swedish applicants have to the European Patent Office, choosing it as the priority office for examining their applications. This possibility triggered the analysis performed in section 4.3. Despite the low number of applications found in the Swedish office, we observe an increase in the number of filings from 2017, presented in

Figure 14, where the filing data of patent applications from inventor applicants or applications with Swedish priority at EPO in the same industry are also presented (item 4.3).

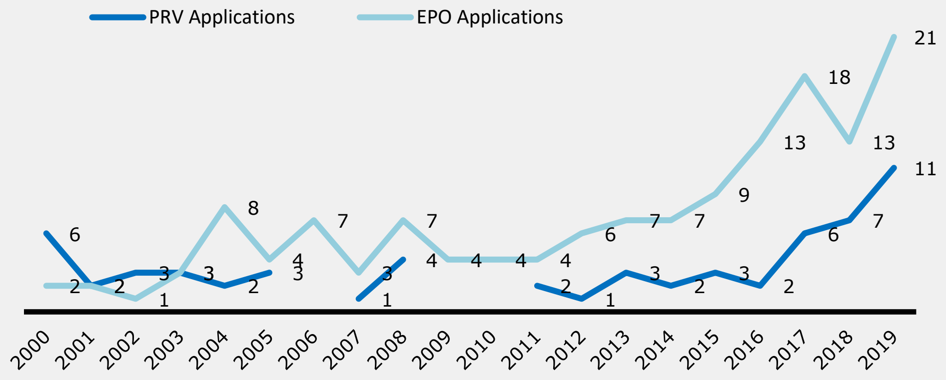

FIGURE 14. DISTRIBUTION OF PATENT APPLICATIONS INVOLVING AI APPLIED TO AIRCRAFT FILED IN SWEDEN (PRV) AND EPO (WITH SWEDISH APPLICANT, INVENTOR, OR PRIORITY) FROM 2000-2019

Figure 15 represents about 82% of the sample and shows the largest applicants in the industry of AI applied to aircraft, with applications filed with the Swedish Patent Office, almost all of them being Swedish companies, except for the British multinational corporation Bae Systems.

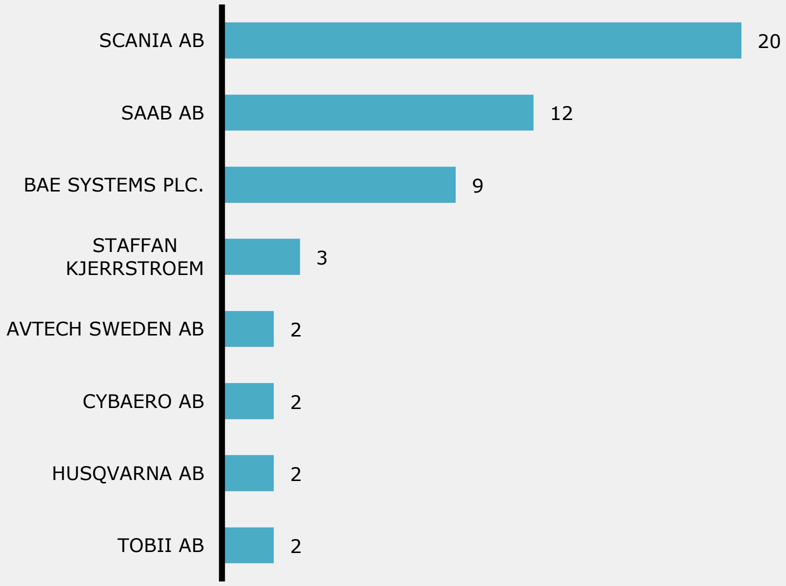

FIGURE 15. MAIN APPLICANTS OF PATENT APPLICATIONS FOR AI TECHNOLOGIES IN THE AERONAUTICAL INDUSTRY WITH FILINGS AT THE SWEDISH PATENT OFFICE IN THE LAST 20 YEARS

The analysis of the categorization of these 63 applications according to the AI dimensions proposed by WIPO identified 4 patent documents related to machine learning technique ("core" dimension of AI) and 2 main functional application categories, namely "computer vision" and "control methods", with 49 and 29 documents respectively. As for the application fields dimension, the main categories found can be identified in Figure 16. Through reading the titles and abstracts of the documents found, a large number of applications related to military technologies, for example, "missile guidance systems", mainly filed by Bae Systems and Saab were observed.

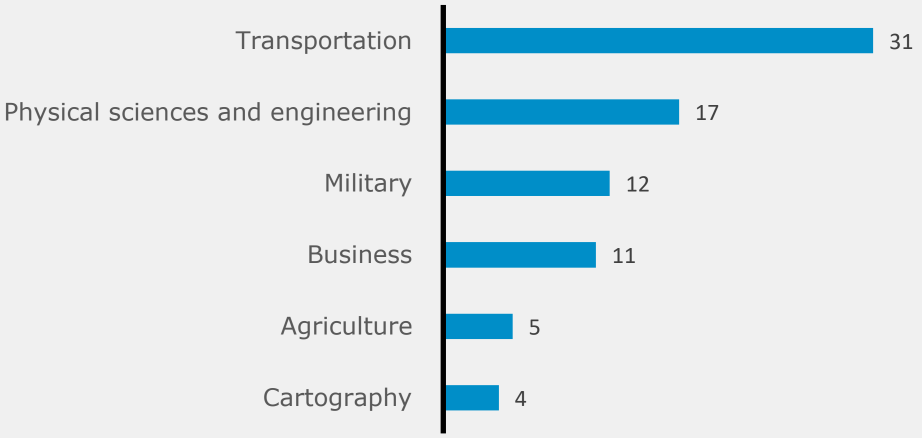

FIGURE 16. FIELDS OF APPLICATION OF PATENT APPLICATIONS INVOLVING AI APPLIED TO THE AERONAUTICAL INDUSTRY FILED IN SWEDEN SINCE THE YEAR 2000

4.3 Patent documents related to AI applied to the Aeronautical industry filed with the European Patent Office – EPO including applicants, inventors, or Swedish priority.

Given the low number of documents filed with the Swedish office using the above strategy, and to understand the form of protection used by Swedish applicants for their inventions in this industry, a new survey was conducted, this time looking for patent documents filed with EPO that presented applicants or inventors of Swedish origin, or even applications that presented Swedish priority (SE).

For this analysis, the search strategy proposed by WIPO was used to recover patent documents related to artificial intelligence technologies, restricting the sample to applications filed between 2000 and 2021. A total of 72,627 AI patent documents filed with EPO in the period were recovered in this stage. Of this set, 2,106 documents were from Swedish applicants or inventors or indicated a Swedish priority. As expected, a much higher number of applications of Swedish origin were filed with EPO than at PRV.

In this set of 2,106 documents related to AI, the methodology was applied to identify the applications that would be related to the Aeronautical industry, which generated a sample of 155 patent documents developed by Swedes and filed with EPO, analyzed below. The distribution of these applications according to their filing date is shown in Figure 14.

Among the 155 applications, 135 are from Swedish applicants. There are also 7 applications with Japanese applicants, 4 American applicants, as well as Chinese, Swiss, English, Danish, and Spanish applicants, indicating possible partnerships (co-ownership of the patents), or Swedish inventors working in foreign companies.

Figure 17 shows the main applicants of technologies filed with EPO that describe technologies involving AI in the aviation industry. These applications have Swedish applicants, inventors, or priority, which would be an indication of the origin of the development of these technologies in Sweden.

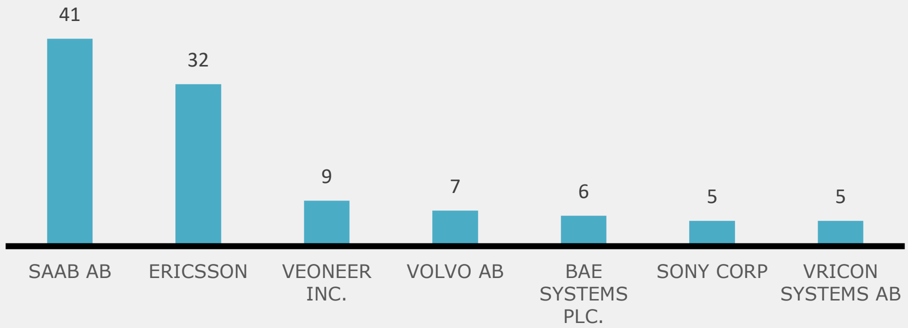

FIGURE 17. NUMBER OF APPLICATIONS FROM THE MAIN APPLICANTS OF TECHNOLOGIES OF SWEDISH ORIGIN FILED WITH EPO RELATED TO AI APPLIED TO THE AERONAUTICAL INDUSTRY

Among Saab's applications, the main classifications found are related to "position, course, and altitude control systems" (for example, autopilot), "air traffic control (ATC) systems", and "pattern recognition and image analysis methods." Regarding the functional applications of AI in these applications, the most identified are "computer vision" and "control methods." Among the applications from Ericsson, the second largest applicant, at least 68% and 47% of the sample deal with "position, course, and altitude control systems" and "unmanned aerial vehicle (UAV)", respectively.

Veoneer and Volvo, which appear in the third and fourth positions, are suppliers of automotive technology. However, the applications identified suggest the possibility of applying these technologies to aviation.

Five of Bae Systems' 6 applications were identified as having a field of application in the armed forces, such as, for example, "combat vehicles" and "missile guidance systems." Sony's applications are all classified as UAV-related, while Vricon Systems is an American company, the result of a joint venture between Saab and DigitalGlobe, a provider of geospatial intelligence software. In the sample of applications filed with EPO, we identified 23 applications related to Machine Learning techniques applied mainly to "computer vision", "Distributed Artificial Intelligence (DAI)", and "control methods" in the area of "transportation."

Figure 18 presents the distribution of applications filed with EPO according to the cooperative patent classification (CPC) that appear in the greatest quantity in the sample. According to this figure, we can note that AI technologies applied to "position, course, or altitude control" are the ones that stand out the most. Other relevant categories are "image or video recognition or understanding", "traffic control systems for aircraft", and "unmanned aerial vehicle (UAV)."

FIGURE 18. NUMBER OF PATENT APPLICATIONS DISTRIBUTED ACCORDING TO THE CPC CLASSIFICATIONS THAT APPEAR MOST IN THE SAMPLE

5 Final Considerations

One of the objectives of HLG is to integrate industrial and academic partners from both countries to develop a Research, Development, and Innovation (P, D & I) agenda, aiming to strengthen relations between institutions, promote and contribute to the creation of networks that ensure long-term collaboration and promote innovation in the area of Aircraft and Defense in Brazil.

This study mapped the patent documents filed in Brazil, Sweden, and EPO (in this case, considering only documents of Swedish origin, identified through the country of the applicant, inventor, or priority), which referred to AI technologies applied to the aviation industry. It is worth mentioning that many applications are from developers related to other industries (e.g. automotive industry), as many of these technologies can have cross-application in several areas. At this point, we also observed that only the patent applications that cited the possibility of application in the Aeronautical industry were considered so that for a deeper analysis of specific technologies, new search strategies can be designed to identify technologies that do not cite application in aviation, but that can be incorporated into the industry (spin-in[12] technologies).

The methodology presented first recovers patent documents related to AI technologies and then identifies from this set those that would have applications in aircraft. In both steps, patent classifications and keywords from these sectors were used. According to the scheme presented in Figure 1, we noted that the use of patent classifications leads to greater assertiveness in document recovery. On the other hand, the use of keywords in the strategy, despite being less assertive (15% of the documents were not directly related to the studied industry), allows the recovery of documents that the classifications did not identify.

[12] Spin-in is a term that is opposed to Spin-out or Spin-off, and means to incorporate and bring into the company, another company (company spin-in) or technology (technology spin-in).

Thus, the proposed strategy allowed the recovery of sets of 624, 63, and 155 AI patent documents potentially applied to the aeronautical industry filed with INPI, PRV, and EPO, respectively. It can be noticed that the number of filings has been increasing over the last few years following the waves of development of AI technologies (see Figure 2 and Figure 14).

Regarding the patenting scenario in Brazil, we noted that most of the applicants in the studied area are foreign, mainly American and French applicants, such as Boeing and Airbus, known as the world's largest OEMs, which are at the top of the list of main applicants (see Figure 3 and Figure 4). Embraer appears as the only resident applicant among the main players identified in the sample, while Saab, a Swedish aviation company, also appears as an important player in the Brazilian aviation scenario using AI.

The patenting scenario in Sweden appears quite different, where most applications have been filed by residents, with Scania and Saab being the main players in the country developing AI technologies potentially applied to the aeronautical industry. Another interesting fact identified in the study was the preferred protection route chosen by Swedish applicants. The number of applications identified in the Swedish Intellectual Property Office – PRV was considerably lower than the applications identified in EPO, and that would be for technologies developed by Swedes, thus indicating the European Patent Office – EPO as the main filing strategy, which would be an indication of interest in extending the protection of these inventions beyond the Swedish territory. As discussed in item 1.2, filing with EPO is a centralized procedure, and therefore faster and more economical, where, after the European patent is granted, it only has to be validated in the countries of interest, considering that there are 38 EPO contracting states (among them Sweden).

Axman & Blomberg (2020) presented the results of a case study within Saab regarding the alignment between the innovation process, technology strategy, and IP asset management (patents, industrial secrets, or publications) in the company, where the results can be generalized to the broader context of companies in the aerospace and defense (A&D) industry. Also in the context of the aerospace and defense industry, according to Cipher (2018, *apud* Axman & Blomberg, 2020), new players are entering the market as new technologies arise. For example, the use of robotics, automation, and human machine interface (HMI) allows new technology companies and start-ups to enter the market. These changes require new ways of dealing with IP, also due to changes in corporate strategies.

São Paulo is a highlight in the Aerospace and Defense industries in Latin America. The State concentrates on the largest aerospace hub in the region, located in the city of São José dos Campos. Among the largest manufacturers in the world, Embraer S.A. is the anchor company of this cluster and, together with other companies that operate in the industry, develops in São Paulo its processes and products for the commercial and executive aviation segments, in addition to integrated solutions for defense, security, and systems.[13] Figure 12 corroborates this statement since it was identified that about 82% of the patent applications of domestic aircraft companies are from applicants located in São Paulo.

The São Paulo economy accounts for almost the totality of the Brazilian aerospace industry, evidencing its predominant character in this industry. In 2018, according to data from the most recent Annual Industrial Survey released by IBGE, São Paulo accounted for 95% of net sales revenues and 96% of the value of industrial transformation of the industry in Brazil.[13] In the present technology radar, we also observe that 63% of the identified applications have applicants from the state of São Paulo.

Embraer is known as a successful Brazilian company in the international market, with a sales volume that ranks it as the third largest manufacturer of commercial aircraft in the world, behind giants Airbus and Boeing. The company is also active in the

[13] https://www.investe.sp.gov.br/setores-de-negocios/aeroespacial-e-defesa/

defense industry, through Embraer Defesa & Segurança. However, as a result of the investment in the training of engineers in the area, as well as the investment in academic research in the industry, Embraer is not the only Brazilian company that produces planes. The country also has several smaller factories producing different types of aircraft, from single-engine recreational aircraft to helicopters, airships, and military drones.[14] This technological radar identified other companies (in addition to Embraer), universities, and research institutes with patent applications related to AI with applications in aviation, in which most of them, however, have only one application filed in the industry, in the analyzed period.

This study evidences Embraer's prominence in the national scenario also when it comes to AI technologies applied to the aviation industry, having been the only resident applicant to be among the largest applicants in the industry identified in the INPI database (see Figure 3). Regarding the low number of resident applicants identified in this study, it is not clear if there is a low number of technology developers in the analyzed industry or if there is a lack of knowledge about the patent system, or yet, if the cost, bureaucracy of filing, maintaining, and defending patents may be discouraging factors for smaller companies. However, companies shall evaluate the benefits that legal protection through patents offers to their enterprise against the maintenance of industrial secrets.

Finally, the proposed methodology can be used to evaluate other markets of interest, as well as identify other important players in the global scenario. Additionally, it is possible to think of defining fields of specific technologies (not necessarily related to Artificial Intelligence) that may be being developed for other sectors and that potentially applies to the aeronautical industry, which can then be evaluated as spin-in technologies for the industry. Furthermore, the results obtained can contribute to the formulation of specific public policies, in addition to assisting the

[14] https://www.cnnbrasil.com.br/business/alem-da-embraer-conheca-outras-fabricantes-que-produzem-avioes-no-brasil/

decision-making process for both applicants and government agents in this technological industry.

The main bibliographic data of the patent applications identified in this study are available in Annex 3.

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Annex 1

ARTIFICIAL INTELLIGENCE SEARCH STRATEGY (adapted WIPO)

Final query= Block 1 OR Block 2 OR Block 3.

Block 1 – List of technology-specific CPC codes involving AI

ACP=(Y10S0706 OR G06N0003 OR (G06N000300) OR (G06N0003002) OR (G06N0003004) OR (G06N0003006) OR (G06N0003008) OR (G06N000302) OR (G06N000304) OR (G06N00030409) OR (G06N00030418) OR (G06N00030427) OR (G06N00030436) OR (G06N00030445) OR (G06N00030454) OR (G06N00030463) OR (G06N00030472) OR (G06N00030481) OR (G06N0003049) OR (G06N000306) OR (G06N0003061) OR (G06N0003063) OR (G06N00030635) OR (G06N0003067) OR (G06N00030675) OR (G06N000308) OR (G06N0003082) OR (G06N0003084) OR (G06N0003086) OR (G06N0003088) OR (G06N0003105) OR (G06N000312) OR (G06N0003123) OR (G06N0003126) OR (G06N000500) OR (G06N0005003) OR (G06N0005006) OR (G06N000502) OR (G06N0005022) OR (G06N0005025) OR (G06N0005027) OR (G06N000700) OR (G06N0007005) OR (G06N000702) OR (G06N0007023) OR (G06N0007026) OR (G06N000704) OR (G06N0007043) OR (G06N0007046) OR (G06N000706) OR G06N0099005 OR G06T220720081 OR G06T220720084 OR G06T00034046 OR G06T0009002 OR G06F001716 OR G05B0013027 OR G05B0130275 OR G05B0013028 OR G05B00130285 OR G05B0013029 OR G05B00130295 OR G05B0221933002 OR G05D00010088 OR G06K0009 OR G10L0015 OR G10L0017 OR (G06F001727) OR (G06F00172705) OR (G06F0017271) OR (G06F00172715) OR (G06F0017272) OR (G06F00172725) OR (G06F0017273) OR (G06F00172735) OR (G06F0017274) OR (G06F00172745) OR (G06F0017275) OR (G06F00172755) OR (G06F0017276) OR (G06F00172765) OR (G06F0017277) OR (G06F00172775) OR (G06F0017278) OR (G06F00172785) OR (G06F0017279) OR (G06F00172795) OR (G06F001728) OR (G06F00172809) OR (G06F00172818) OR (G06F00172827) OR (G06F00172836) OR (G06F00172845) OR (G06F00172854) OR (G06F00172863) OR (G06F00172872) OR (G06F00172881) OR (G06F0017289) OR (G06F001730029) OR (G06F001730032) OR (G06F001730035) OR (G06F001730247) OR (G06F00173025) OR (G06F001730253) OR (G06F001730256) OR (G06F001730259) OR (G06F001730262) OR (G06F001730522) OR (G06F001730525) OR (G06F001730528) OR (G06F00173053)OR G06F001730401 OR G06F00173043 OR G06F001730654 OR G06F001730663 OR G06F001730666 OR G06F001730669 OR G06F001730672 OR G06F001730684 OR G06F001730687 OR G06F00173069 OR G06F001730702 OR (G06F001730705) OR (G06F001730707) OR (G06F00173071) OR (G06F001730713) OR (G06F001730731) OR (G06F001730734) OR (G06F001730737) OR (G06F001730743) OR (G06F001730746) OR (G06F001730784) OR (G06F001730787) OR (G06F00173079) OR (G06F001730793) OR (G06F001730796) OR (G06F001730799) OR (G06F001730802) OR

(G06F001730805) OR (G06F001730808) OR (G06F001730811) OR (G06F001730814) OR G06F001924 OR G06F0019707 OR (G01R00312846) OR (G01R00312848) OR G01N022011296 OR G01N00294481 OR G01N00330034 OR G01R00313651 OR G01S0007417 OR (G06N0003004) OR (G06N0003006) OR (G06N0003008) OR G06F0111476 OR G06F00112257 OR G06F00112263 OR G06F001518 OR G06F022074824 OR G06K00071482 OR G06N0007046 OR G11B002010518 OR G10H02250151 OR G10H02250311 OR G10K022103024 OR H01J0223730427 OR H01M000804992 OR H02H00010092 OR H02P00210014 OR H02P00230018 OR H03H020170208 OR H03H222204 OR H04L020125686 OR H04L0202503464 OR H04L0202503554 OR H04L0250254 OR H04L002503165 OR H04L004116 OR H04L004508 OR (H04N00214662) OR (H04N00214663) OR (H04N00214665) OR (H04N00214666) OR H04Q02213054 OR H04Q0221313343 OR H04Q02213343 OR H04R0025507 OR G08B0029186 OR B60G026001876 OR B60G026001878 OR B60G026001879 OR B64G02001247 OR E21B020410028 OR B23K0031006 OR B29C294576979 OR B29C0066965 OR B25J0009161 OR (A61B00057264) OR (A61B00057267) OR Y10S0128924 OR Y10S0128925 OR F02D00411405 OR F03D0007046 OR F05B2270707 OR F05B02270709 OR F16H020610081 OR F16H020610084 OR B60W003006 OR (B60W003010) OR (B60W003012) OR (B60W003014) OR (B60W0030143) OR (B60W0030146) OR (B60W003016) OR (B60W0030162) OR (B60W0030165) OR (B60W003017) OR B62D00150285 OR (G06T220730248) OR (G06T220730252) OR (G06T220730256) OR (G06T220730261) OR (G06T220730264) OR (G06T220730268) OR G06T220730236 OR G05D0001 OR A61B0057267 OR F05D02270709 OR G06T220720084 OR G10K22103038 OR G10L002530 OR H04N00214666 OR A63F001367 OR G06F00172282)

Block 2 – List of specific keywords related to AI (searched in the Title, Abstract, or claims)

CTB=(((ARTIFIC* OR COMPUTATION*) NEAR2 INTELLIGEN*) OR (NEURAL NEAR2 NETWORK*) OR (NEURAL NETWORK*) OR (NEURAL NETWORK*) OR (BAYES* NEAR2 NETWORK*) OR BAYESIAN-NETWORK* OR (BAYESIAN NETWORK*) OR (CHATBOT?) OR (DATA NEAR2 MINING*) OR (DECISION NEAR2 MODEL?) OR (DEEP NEAR2 LEARNING*) OR DEEP-LEARNING* OR (DEEP LEARNING*) OR (GENETIC NEAR2 ALGORITHM?) OR ((INDUCTIVE NEAR2 LOGIC) ADJ2 PROGRAMM*) OR (MACHINE NEAR2 LEARNING*) OR (MACHINE LEARNING*) OR MACHINE-LEARNING* OR ((NATURAL ADJ2 LANGUAGE) NEAR2 (GENERATION OR PROCESSING)) OR (REINFORCEMENT NEAR2 LEARNING) OR (SUPERVISED NEAR2 (LEARNING* OR TRAINING)) OR SUPERVISED-LEARNING* OR (SUPERVISED LEARNING*) OR (SWARM NEAR2 INTELLIGEN*) OR SWARM-INTELLIGEN* OR (SWARM INTELLIGEN*) OR (UNSUPERVISED NEAR2 (LEARNING* OR TRAINING)) OR UNSUPERVISED-LEARNING* OR (UNSUPERVISED LEARNING*) OR (SEMISUPERVISED NEAR2 (LEARNING* OR TRAINING)) OR SEMI-SUPERVISED-LEARNING OR (SEMI SUPERVISED LEARNING*) OR CONNECTIONIS* OR (EXPERT NEAR2 SYSTEM?) OR (FUZZY NEAR2 LOGIC?) OR TRANSFER-LEARNING OR “TRANSFER LEARNING” OR (TRANSFER NEAR2 LEARNING) OR

(LEARNING NEAR4 ALGORITHM?) OR (LEARNING NEAR2 MODEL?) OR (SUPPORT VECTOR MACHINE?) OR (RANDOM FOREST?) OR (DECISION TREE?) OR "GRADIENT TREE BOOSTING" OR XGBOOST OR ADABOOST OR RANKBOOST OR "LOGISTIC REGRESSION" OR "STOCHASTIC GRADIENT DESCENT" OR (MULTILAYER PERCEPTRON?) OR "LATENT SEMANTIC ANALYSIS" OR "LATENT DIRICHLET ALLOCATION" OR (MULTI-AGENT SYSTEM?) OR (HIDDEN MARKOV MODEL?))

Block 3 – CPC or IPC code lists or non-specific FI/F-terms classes, controlled by AI keywords

((ACP=(G06T0007 OR G06T000120 OR G10L0013 OR G10L0025 OR G10L0099 OR (G06F001714) OR (G06F0017141) OR (G06F0017145) OR (G06F0017147) OR (G06F0017148) OR G06F0017153 OR (G10H2250005) OR (G10H2250011) OR (G10H2250015) OR (G10H2250021) OR G06F01750 OR (G06Q003002) OR (G06Q00300201) OR (G06Q00300202) OR (G06Q00300203) OR (G06Q00300204) OR (G06Q00300205) OR (G06Q00300206) OR (G06Q00300208) OR (G06Q00300209) OR (G06Q00300211) OR (G06Q00300212) OR (G06Q00300213) OR (G06Q00300214) OR (G06Q00300215) OR (G06Q00300216) OR (G06Q00300217) OR (G06Q00300219) OR (G06Q00300221) OR (G06Q00300222) OR (G06Q00300223) OR (G06Q00300224) OR (G06Q00300225) OR (G06Q00300226) OR (G06Q00300227) OR (G06Q00300228) OR (G06Q00300229) OR (G06Q00300231) OR (G06Q00300232) OR (G06Q00300233) OR (G06Q00300234) OR (G06Q00300235) OR (G06Q00300236) OR (G06Q00300237) OR (G06Q00300238) OR (G06Q00300239) OR (G06Q00300241) OR (G06Q00300242) OR (G06Q00300243) OR (G06Q00300244) OR (G06Q00300245) OR (G06Q00300246) OR (G06Q00300247) OR (G06Q00300248) OR (G06Q00300249) OR (G06Q00300251) OR (G06Q00300252) OR (G06Q00300253) OR (G06Q00300254) OR (G06Q00300255) OR (G06Q00300256) OR (G06Q00300257) OR (G06Q00300258) OR (G06Q00300259) OR (G06Q00300261) OR (G06Q00300262) OR (G06Q00300263) OR (G06Q00300264) OR (G06Q00300265) OR (G06Q00300266) OR (G06Q00300267) OR (G06Q00300268) OR (G06Q00300271) OR (G06Q00300272) OR (G06Q00300273) OR (G06Q00300274) OR (G06Q00300275) OR (G06Q00300276) OR (G06Q00300277) OR (G06Q00300278) OR (G06Q00300279) OR (G06Q00300281) OR (G06Q00300282) OR (G06Q00300283) OR (G06Q00300284) OR (G07C0009 OR G06F0021)) OR IC=(A61B0005 OR A63F001367 OR B23K0031 OR B25J000916 OR B25J000918 OR B25J000920 OR B29C065 OR B60W003006 OR B60W003010 OR B60W003012 OR (B60W003014) OR (B60W003016) OR (B60W0030165) OR (B60W003017) OR B62D001502 OR (B64G000124) OR (B64G000126) OR (B64G000128) OR (B64G000132) OR (B64G000134) OR (B64G000136) OR (B64G000138) OR E21B0041 OR (F02D004114) OR (F02D004116) OR F03D000704 OR F16H0061 OR (G01N002944) OR (G01N002946) OR (G01N002948) OR (G01N002950) OR (G01N002952) OR G01N0033 OR (G01R003128) OR (G01R003130) OR (G01R0031302) OR (G01R0031303) OR (G01R0031304) OR (G01R0031305) OR (G01R0031306) OR (G01R0031307) OR (G01R0031308) OR (G01R0031309) OR (G01R0031311) OR (G01R0031312) OR (G01R0031315) OR (G01R0031316) OR (G01R00313161) OR (G01R00313163) OR (G01R00313167) OR

(G01R0031317) OR (G01R00313173) OR (G01R00313177) OR (G01R00313181) OR (G01R00313183) OR (G01R00313185) OR (G01R00313187) OR (G01R0031319) OR (G01R00313193) OR (G01R003136) OR (G01R0031364) OR (G01R0031367) OR (G01S000741) OR (G05B001302) OR (G05B001304) OR G06F001114 OR (G06F001122) OR (G06F001124) OR (G06F001125) OR (G06F001126) OR (G06F0011263) OR (G06F0011267) OR (G06F001127) OR (G06F0011273) OR (G06F0011277) OR G06F001518 OR G06F001714 OR G06F001715 OR G06F01716 OR G06F001720 OR G06F001727 OR G06F001728 OR G06F001924 OR G06K000714 OR G06K0009 OR G06N0003 OR G06N0005 OR G06N0007 OR G06N0099 OR G06T000120 OR G06T000140 OR G06T000340 OR G06T0007 OR G06T0009 OR (G08B002918) OR (G08B002920) OR (G08B002922) OR (G08B002924) OR (G08B002926) OR (G08B002928) OR G10L0013 OR G10L0015 OR G10L0017 OR G10L0025 OR G10L0099 OR (G11B002010) OR (G11B002012) OR (G11B002014) OR (G11B002016) OR (G11B002018) OR G16H005020 OR H01M000804992 OR H02H0001 OR H02P0021 OR H02P0023 OR (H03H001702) OR (H03H001704) OR (H03H001706) OR H04L001224 OR H04L001270 OR H04L0012751 OR (H04L002502) OR (H04L002503) OR (H04L002504) OR (H04L002505) OR (H04L002506) OR (H04L002508) OR (H04L002510) OR (H04L002512) OR (H04L002514) OR (H04L002517) OR (H04L002518) OR (H04L002520) OR (H04L002522) OR (H04L002524) OR (H04L002526) OR H04L002503 OR H04N0021466 OR H04R025 OR G07C0009 OR G06F0021) OR FIC=((G06N000302) OR (G06N000304) OR (G06N000304127) OR (G06N000304136) OR (G06N000304145) OR (G06N000304154) OR (G06N000304190) OR (G06N000304E) OR (G06N000304F) OR (G06N000304Z) OR (G06N000306) OR (G06N0003063) OR (G06N0003067) OR (G06N000308) OR (G06N000308120) OR (G06N000308140) OR (G06N000308160) OR (G06N000308180) OR (G06N000308Q) OR (G06N000308Z) OR (G06N000310) OR G06N000308 OR G06N0099 OR G06N000704 OR G06K0009 OR G06K000900 OR G10L0013 OR G10L0025 OR G10L0015 OR G10L0017 OR G10L0099 OR G06F001727 OR G06F001728 OR (G06F001730180A) OR (G06F001730180B) OR (G06F001730180C) OR G06F 17/30210A OR G06F 17/30210D OR G06F 17/30220A OR G06F 17/30310C OR G06F 17/30330C OR G06K 9 OR G06F 19/00130 OR G06N 3/00140 OR G06F 11/14676 OR G06F 11/22657 OR G06F 11/22663 OR G06K 7/14082 OR H01M 8/04992 OR H04N 21/466 OR (B60W 30/06) OR (B60W003010) OR (B60W003012) OR (B60W003014) OR (B60W003016) OR (B60W0030165) OR (B60W003017) OR F02D004114310H) OR FTC=(5B078* OR 5B178* OR 5B064* OR 5L096FA* OR 5L096GA* OR 5L096HA* OR 5L096JA* OR 5L096KA* OR 5L096MA07 OR 5B043* OR 5B064* OR 5B057CH* OR 5B057DA* OR 5B057DC* OR 5H004KD23 OR 5H004KD31 OR 5H004 KD32 OR 5H004KD33 OR 5H004KD35 OR 5H004KD63 OR 5H301DD02 OR 5H301JJ* OR 5H301LL* OR 5D045* OR 5D015* OR 5B056BB* OR 5B056HH03 OR 5B056HH05 OR 5B109QA* OR 5B109RD02 OR 5B109RD03 OR 5B091* OR 5B075NK3* OR 5B075PP04 OR 5B075PP24 OR 5B075PP25 OR 5B075QP* OR 5B075QT04 OR 5B075QT05 OR 5B064* OR 5L049DD04 OR 5J070BF16 OR 5B078* OR 5B048DD12 OR 5K030KA07 OR 5K030KA18 OR 5K030KA20 OR 5C164PA43 OR 5C164YA12 OR 5C087GG02 OR 3D241AF05 OR 3D241AF07 OR 3D241BA* OR 3D241CE05 OR 3D241CE06 OR 3D241CE08 OR 3D241CE10 OR 3C707KT11 OR 3C707 LW1* OR 4C117XJ31 OR 4C117XK11 OR 3G301ND2* OR 3G301ND3* OR 3G301ND43 OR 3J552TA11 OR 3J552TA12 OR 3J552TA18 OR 3J552TA19 OR 3J552TA20)) AND CTB=(CLUSTERING OR

(COMPUT* CREATIVITY) OR (DESCRIPTIVE MODEL?) OR (INDUCTIVE REASONING) OR OVERFITTING OR (PREDICTIVE NEAR2 (ANALYTICS OR MODEL?)) OR (TARGET NEAR2 FUNCTION?) OR ((TEST OR TRAINING OR VALIDATION) ADJ2 DATA ADJ2 SET?) OR BACKPROPAGATION? OR SELF-LEARNING OR "SELF LEARNING" OR (OBJECTIVE FUNCTION?) OR (FEATURE? SELECTION) OR (EMBEDDING?) OR (ACTIVE LEARNING) OR (REGRESSION MODEL?) OR ((STOCHASTIC OR PROBABILIST*) ADJ3 (APPROACH* OR TECHNIQUE? OR METHOD? OR ALGORITHM?)) OR (RECOMMEND* SYSTEM?) OR ((TEXT OR SPEECH OR HAND WRITING OR FACIAL OR FACE? OR CHARACTER?) NEAR2 (ANALYSIS OR ANALYTIC? OR RECOGNITION))))

Annex 2

THESAURUS USED TO DEFINE AIRCRAFT-RELATED APPLICATIONS

Subset of "keywords" related to the aeronautical industry

Specific words and expressions		Related words and expressions
Aeronautics	Fault Detection Isolation and Recovery	Aerospace
Aerial	FDIR	Atmosphere
Aeroplane	Flight	Auto-Pilot
AEW&C[15]	Fuel Efficiency Optimization	Collision Prevention Systems
Aircraft	Helicopter	Image Based Navigation
Airplane	Landing	HMI
Air-Traffic Control	Micro-Aerial Vehicle	Human Machine Interface
Air-Traffic Management	ROAAS[16]	Map Display
ATTOL[17]	Unmanned Aerial Vehicles	Simulator
Auto-Land	UAV	Guidance and Navigation Control
Aviation	Virtual Pilot Assistant	GNC
Avionics	Take-Off	SAR Image Processing
Detect Sense And Avoid	VTOL[18]	Smart Maintenance
Drone	windshear	Transponder

15 AEW&C, stands for Airborne Early Warning and Control
16 Runway Overrun Awareness and Alerting System
17 Autonomous Taxi, Take-Off and Landing
18 Vertical Take-Off and Landing

Subset of IPC and CPC Classifications with application to the aerospace industry

B21D005392; B23B221504; B23C221504; B23P270001; B32B260518; B60F000502; B60R20210093; B60T0008325; B60V000308; B63B003550; B63B003552; B63B003553; B63G0011; B64B; B64C; B64D; B64F; C10N204013; C10N2240121; D06N2211267; E05Y2900502; F01P0007023; F02C000944; F05B2220303; F05B222031; F05B227010815; F05D2220323; F05D22701022; F16N221008; F21W210730; F21W211106; F41F000306; F41G0007; F41H001102; G01C0005005; G01C0009005; G01C0023005; G01M0001125; G01M0001127; G01M00050016; G01S000116; G01S000118; G01S001379; G01S001387; G01S001389; G01S0013913; G01S00139303; G01S0013933; G01S0013953; G01S0017933; G01S001915; G01S220106; G01S2205003; G01S2205005; G01V000316; G01V0005025; G05D00010083; G05D00010202; G05D0001042; G05D00010607; G05D00010808; G05D00010858; G05D00010866; G05D0001101; G05D0001102; G05D0001104; G05D00011064; G08B00131965; G08G0005; G09B000908; G09B00091; G09B000912; G09B000916; G09B00092; G09B00093; G09B00094; G09B00095; G09B0019165; G09G238012; G10K22101281; H01Q0001285; H02P210130; H04B000718506; H04L20124028; Y02P0070585; Y02T005000; Y02T005058; Y02T005060; Y02T005067; Y02T0050678; Y02T0050823; Y02T009036; Y02T009044; Y10S006205; Y10S011192; Y10S0180904; Y10S026102; Y10S032033

Subset of foreign and national companies operating in the aerospace industry

Foreign Companies				Brazilian Companies
Aernnova	Curtiss-Wright	Kf Aerospace	Recaro Aircraft Seating	Acs Aviation
Aerobotics	Daher	Kittyhawk	Relativity Space	Aeroalcool
Aerojet Rocketdyne	Dassault Aviation	Kongsberg	Rockwell Collins	Aerobravo
Aerospace Corporation	Diehl Aerosystems	Korea Aerospace Industries	Rolls-Royce	Aeropepe
Aerovironment	Droneseed	Korean Air Aerospace Division	Rosemount Aerospace	Aerotron
Aidc	Ducommun	L-3 Communications Avionics Systems	Rostec State Corporation	Airship Do Brasil
Airbus	Eaton	L-3 Technologies	Ruag	Avibras
Airgility	Elbit Systems	Latécoère	Saab	Avio Do Brasil
Airobotics	Esterline	Leonardo	Safe Flight Instrument	Collins Aerospace
Airscout	European Aeronautic Defence And Space	Liebherr	Safran Aircraft	Comaf
Allegheny Technologies	Facc	Lisi	Sandel Avionics Llc	Desaer
American Robotics	Figeac Aéro	Lockheed Martin	Shinmaywa	Eleb

Artificial Intelligence in the Aeronautical Industry

Foreign Companies				Brazilian Companies
Amphenol	Flir Systems	Lord Corporation	Sierra Nevada Corporation	Embraer
Arconic	Garmin	Magellan Aerospace	Skf	Fly
Asco Industries	Ge Aviation Systems	Martin-Baker	Skyrobot	Flyer
Astronics Corporation	Gec Avionics	Maxar Technologies	Skyx	Gol Linhas Aéreas
Aurora Flight Services	General Dynamics	Mda	Snecma	Helibras
Avic	General Electric	Meggitt	Solvay Group	Inpaer
Bae Systems	Gkn	Mitsubishi Aircraft Industries	Sonaca	Ipe Aeronaves
Ball Aerospace	Gulfstream Aerospace	Mitsubishi Heavy Industries	Space Data Corporation	Novaer
Barnes Aerospace	Harris	Moog	Spacex	Octans Aircraft
Bell Helicopter	Heico	Mtu Aero Engines	Spirit Aerosystems	Opto
Bluestaq	Héroux-Devtek	Nasa	St Engineering	Orbital
Boeing	Hexcel	Nordam Group	Standardaero	Paradise Indústria Aeronáutica
Boening	Hindustan Aeronautics	Northrop Grumman	Subaru Corporation	Saipher
Bombardier	Honeywell	Office National D'etudes Et De Recherches Aérospatiales	Teledyne Technologies	Sat
Boom Supersonic	Hutchinson	Panasonic Avionics	Textron	Sccon Geospatial

Foreign Companies				Brazilian Companies
Cae	Ihi	Parker Hannifin	Thales	Scoda Aeronáutica
Chromalloy	Iris Automation	Pilatus	Transdigm	Seamax
Cmc Eletronics	Israel Aerospace Industries	Planetlabs	Triumph Group	Siatt
Cms Aeronautica	Itt Corporation	Pratt & Whitney	Turkish Aerospace Industries	Skydrones Tecnologia Avionica
Cobham	Jamco	Praxair	United Aircraft	Stella Tecnologia
Collins Aerospace	Kaiser Aluminum	Precision Castparts	United Technologies	Visiona Tecnologia Espacial
Constellium	Kaman Aerospace	Qinetiq	Viking Air	Voa
Crane Aerospace	Kawasaki Heavy Industries	Raytheon	Woodward	Volato