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ACARE and Flight Path 2050 Goals for Maintaining and Extending Aviation Industrial Leadership

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Abstract

The European strategy for aviation Flightpath 2050 envisaged that by 2050 the region should maintain and extend its industrial leadership in aviation. In order to maintain and extend its leading position in the aeronautical sector, the European industry must master each of a wide range of technologies, and must collaborate in their integration in an aircraft design and development programme. A collaborative approach to innovation is key to achieve these goals. The main purpose of ACARE is to initiate cooperation among stakeholders, aimed at achieving the goals Flightpath 2050.

For achieving ACARE goals, one of the purposes of European Union funded-project PARE project research is to evaluate the European potential for future long-term technological leadership. Two different approaches and methods are used in this paper to analyse the structure of the technological innovation networks in European aviation and to characterise the map of the European Aviation Technology Space. On one side, we perform a bibliometric network analysis of aviation research scientific publications, based on a keywords co-occurrence analysis method, to map the European aerospace collaboration structures. Complementarily, we perform patent analysis to evaluate the innovation capacity of the European industry in the cutting edge technologies previously identified.

1. Introduction

Aviation is a leading industry worldwide and a very a specialized sector that has become one of the drivers of global economy, society development and wellbeing. Governments, institutions, associations and companies acknowledge the significance of the aviation business in the sustainable development of the world as we know it. Only in Europe the industry generates more than 800,000 employments, is the source of more than 220,000 million euros in innovative products and services, and invests more than 20,000 million euros in Research and Development (R & D) in 2016 [1] [2]. These figures allow affirming that the aeronautical industry is an important contributor to the economic welfare of Europe. Despite this strength, aeronautics has still to face important challenges related its sustainability and performance in an evolving and demanding technological environment. Aviation is moving to a new level of development in the context of globalization, increasingly fiercer industrial competition but also cooperation and partnerships, as well as an unstoppable technological investment growth.

The Flightpath 2050 strategy envisaged a vision of the industrial future synthesised in three main goals at the Flightpath 2050. By 2050: "The whole European aviation industry is strongly competitive, delivers the best products and services worldwide and has a share of more than 40% of its global market.

- Europe will retain leading edge design, manufacturing and system integration capabilities and jobs supported by high profile, strategic, flagship projects and programmes covering the whole innovation process from basic research to full-scale demonstrators.
- Streamlined systems engineering, design, manufacturing, certification and upgraded processes have addressed complexity and significantly decreased development costs (including a 50% reduction in the cost of certification). A leading new generation of standards is created."

These impressive achievements across the full range of aeronautical products depends on:

DOI: 10.13009/EUCASS2019-843

- Leading-edge technologies in all the sectors involved in the design of air vehicles;
- Cooperation to incorporate of all these cutting-edge knowhow and technologies in effective production and certification aircraft programmes.

Technological innovation has always been seen as the key asset of the industry to face growth challenges. Successfully design, develop and product an aircraft is a complex and demanding process that requires to master a wide range of technologies. But scientific knowledge is not enough, industry is required to collaborate and integrate all these expertise through the aircraft design, development and production program. A cooperative attitude to innovation is crucial to attaining these objectives.

In the European Union, the Advisory Council for Aeronautics Research in Europe (ACARE) plays a key role in the long-term strategy for research aimed at enlarging the European industrial leadership in the aviation industry. The main task of ACARE is to foster cooperation between stakeholders, aimed at achieving the goals of Flightpath 2050. To analyse the fulfilment of the goals outlined in the Flightpath 2050, at the present time, on the initiative of the partners of the European Union funded-project PARE - Perspectives for Aeronautical Research in Europe [3], research is being conducted to determine the level of progress, gaps and barriers for each of these objectives, and to develop recommendations for their elimination.

In particular, one of the research tasks in the PARE project is the assessment of the potential for future long-term technological innovation. This assessment is performed through the characterisation of a map of the Aviation Technology Space, and provides hindsight into two complementary issues:

- The study of the capability of the aviation industry to dominate and innovate in key technological areas.
- The study of the aviation collaboration structures to determine up to what extent they allow to co-operate and add up expertise and work into the innovation path.

The aim of this paper is to examine the structure and organization of the technological innovation networks in the aviation domain and to build the map of the “Aviation Technology Space”. Two complementary methods are applied to achieve this aim. First method consists of a bibliometric network analysis of scientific aviation research publications. By applying keyword co-occurrence examination we produce a map the aerospace research collaboration structures. Second method consists of patent analysis and allows to quantify the capability of the industry to innovate and develop cutting-edge technologies, and to picture how this capability is spread worldwide. Based on this double analysis, recommendations for research and innovation are issued.

2. Methodology

Aviation is a complex system with highly inter-related technologies, whose relations can be mapped as a network. The structure of this network can help us understand the properties of technologies and their research, if mapped with precision. [4] [5] [6]. Moreover, technologies referring to similar knowledge are somehow related and close in the technology space [7].

These properties permit to describe a space of technology and innovation as a network, that can be analysed with network analyses methods. This network type of analysis of the Aviation Technology Space provide hindsight into how aerospace collaboration structures as a whole behaves and whether the industry can master key technological areas and innovate on them.

In this paper we have followed a three step mythology, consisting in the:

- Identification of key technological.
- Selection of innovation indicators and proper data.
- Assessment of technology network's structures.

2.1. Key technological areas.

Eleven technological areas have been identified essential for mastering the design of aeronautical complex products such any type of air vehicle [8]. All of them require high level of expertise, because low performances in any of them can paralyze the design of an airplane and condemn its market perspective. Additionally In addition, these technologies must be ready for integration in new competitive products at any time required in a new development programme. These areas are presented in figure 1.

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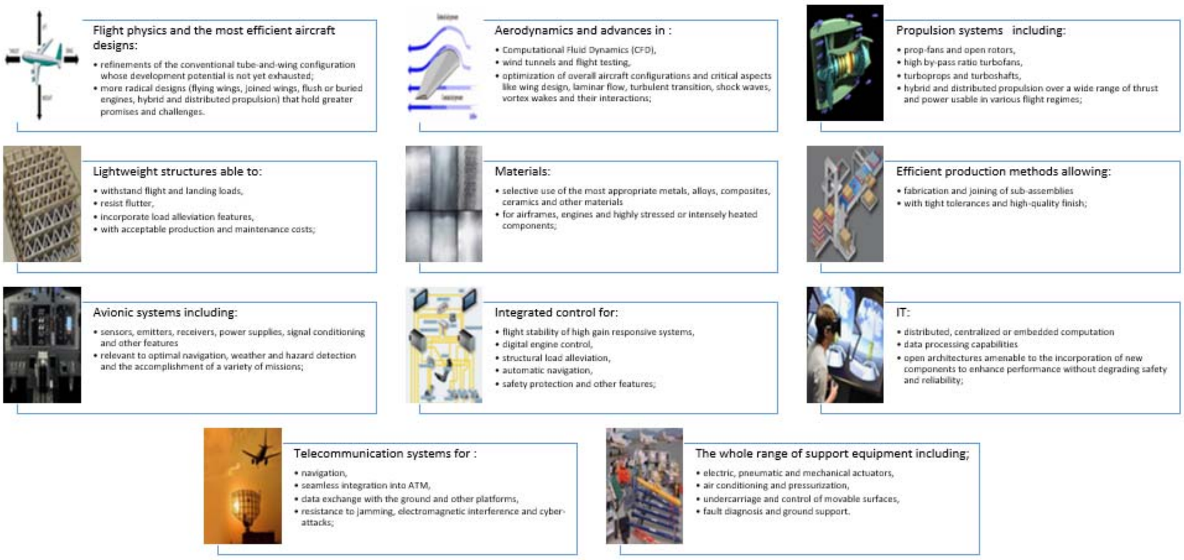

Figure 1. Key technological areas for the competitiveness of the aerospace industry.

2.2. Indicators and sources of data.

The technology space is drawn in this research from publications and patents, which are classified by experts into domains of knowledge relevant for aviation products. The analysis of the patents and publications by technological area, permits to derivative interrelationship and proximity between technology classes and research structures. From this analysis innovation gaps and research recommendations will be identified.

The study is based on two big data bases, one of scientific and technical publications and another one of patents. Scientific and technical publications were obtained from the Web of Science (WoS) Database. A query was done looking for the "WC= ("Aerospace, Engineering")". A total period of 10 years was cover and a total of 57.982 publications were downloaded. Scientific Coverage of WoS has been validated in previous studies [9]. The assessment performed is fundamentally graphic and all visuals in this study for publication analysis have been prepared by using VOSviewer software [9].

Analysis of patents is now more straight forwards, thanks to the spread of electronic patents database, and more advance methods to exploit the text included in the patents. These are the outcome of many of R&D activities and denote the features of technology. The potential of its analysis is great from several points of view, including geographical, temporal, sectoral or technological distribution of inventions [10]. [11]. The second data base used was the Derwent Innovations Index Database. The database classify the patents into three overall areas and 20 categories. The overall areas correspond to Electrical and Electronic Sections (S - X); Engineering Sections (P - Q); Chemical Sections (A - M). Categories are additional divided into classes, coding with a letter and two digits. A deep search for "aviation" was performed, returning a total of 23,508 patents for the analysis. The patent analysis has been performed with the VantagePoint software [12], and include some initial pre-processing involving filtering, and pre-specified thesaurus and fuzzy clustering

2.3. Assessment of technology network's structures.

Two different methods were combined in the analysis of the structure of the technological aviation innovation networks. On one side, we perform a bibliometric network analysis of aviation research scientific publications, by considering co-occurrence of keywords, to map the European aerospace collaboration structures. Complementarily, we perform patent analysis to evaluate the innovation capacity of the European industry in the cutting edge technologies previously identified.

Bibliometric analysis is a well-known method for inferring the dynamic forces of a scientific field [13]. Among the various possible techniques we applied co-word analysis. This is a technique developed late in the 70s, that has become the most spread one [14]. Typical keyword co-occurrence analysis is illustrated in figure 2. The foundation of co-occurrence analysis is that words present in the same document and representing a particular research theme have a relevant relationships [15]. This relationship is proportional to the words coincidence.

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This methods has been used before in aviation for different purposes, although its application is still limited. Cooperation networks among engineering Aerospace educational institutions are studied at [21]. Intellectual logic applied by specialised aviation journals has been outlined by this methods. [16]. Some researchers have attempted extract research trends using keywords co-occurrence over research public funded projects [17]. Particularly relevant is the analysis, in [20], of 12 years of WoS aerospace engineering articles to study co-occurrence network at Chinese research organizations.

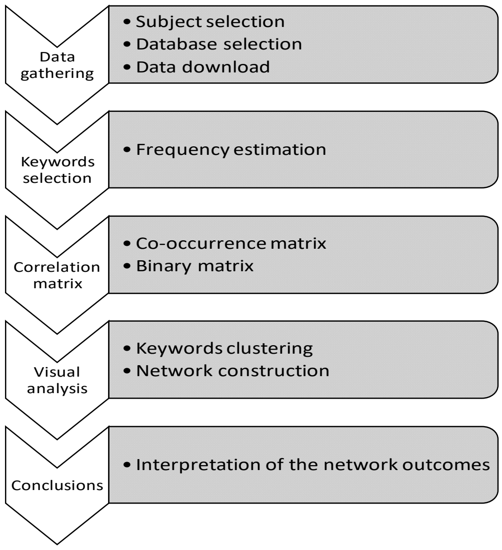

Figure 2. Process of co-occurrence analysis.

Patent analysis is also a widely used to evaluate outcomes of R&D particularly transfer processes or dissemination of knowledge [22]. It can be accomplished from different points of view, for example micro vs macro analysis. The micro level used to asses issues like forecasting [24], information diffusion [23], or competitive analysis [25]. Macro level looks at the issues such competition or collaboration between nations [26]. The scope of applications is quite broad, including predict directions of technological evolution [30], assessment of diffusion [29], time-lag between research activities [28], etc, Traditionally, two main approaches can be distinguished: content-based approaches and citation-based. One measures similarity of contents between pairs using text mining techniques and the other considers just citations between two patents [31]. In this paper we apply a new approach that overcomes limitations of the previous ones, network-based patent analysis. This technique shows the relationship among patents as a graphic network based on text mining [32]. Figure 3 present the typical steps in the process. Some relevant precedents have inspire our work. Nakamura's [33] map aerospace engineering comparatively with automotive, finding similar technology fields for improvement in both aviation and automotive. Patent analysis is used at [34] to forecast technology for green aviation, particularly fuel cell and engines.

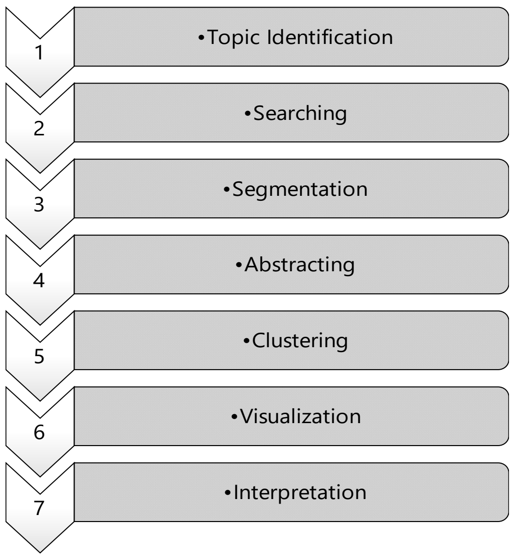

Figure 2. Process pf network patent analysis.

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3. Assessment of the European aerospace collaboration structures based on web of science database.

In this section, co-occurrence analysis is applied for understanding the dynamics of research in aviation. The analysis is performed at three hierarchical levels:
- State,
- Organisation, and
- WoS research category.

The study proves the presence of international scientific collaboration networks at the level of countries and at the level of institutions. The study also sort the main aerospace sub-fields of on which those international scientific collaboration networks are involved.

3.1. International Collaboration Networks

The first visual is presented to convey an understanding of the international aviation collaboration network. From the scientific field co-occurrence analysis, 6 main clusters are identified. The co-word bibliometric network studied is a weighted network. The edges indicate a relation between two nodes, as well as the strength of the relation. In Figure 3, the main clusters of the international collaboration network are indicated with different colors, and the publication frequency is indicated by the size of the node. It identifies countries with weighted direct citation links.
In Figure 3, the highest publication frequency takes place in the USA, followed by China and the European Union. USA presents the top Weighted Degree (WD) value, WD = 3217, China accounts for a WD of 1287, and Germany, England, Italy, France, and Netherlands complete the list of the 7 top countries with a WD higher than 1200. European countries dominate four of the 6 clusters; the two exceptions are led by Israel and the USA.
Germany (WD= 1925), England (WD=1579), France (WD=1499), Italy (WD=1333), Netherlands (WD=1296), Spain(763), Belgium (WD=431) and Switzerland (WD=395) can be identified as the main actors in their clusters.
This structure of clusters highlights how the technological capabilities in aerospace engineering are spread or concentrated. Research capabilities and knowledge are homogeneously spread, with a clear geographical correlation, into four highly specialized clusters. However, national aerospace technological capabilities may not be easily collectivized. Therefore, aviation needs to pursue a dual policy of promoting excellence in the different aerospace subfields while also aggregating their information. On one side, research policy should support every cluster's continued excellence in different subfields. On the other side, research policy must facilitate the aggregation of the diverse experience and knowledge in each subfield into a shared platform for the aviation industry. It has to be considered that although national technological capabilities of aerospace engineering may not be collectivized, information and experience may differ in this regard. Therefore, innovation creation policy should reinforce the spread of knowledge while maintaining its mission orientation. Implementation of multi-objective innovation measures, both diffusion-oriented and mission-oriented, will be more suitable for maintaining excellence in aviation than single-objective policies.
The analysis of representative countries in the European clusters is also important, particularly with respect to EU-13[1] countries, which, with the exception of Poland, are practically absent from the international collaboration network. This result is coherent with the level of participation of EU-13 countries in European Research funded initiatives. In 2007, ACARE published a high-level report on the aeronautical research capabilities of the twelve most recent members of the European Union. The report included recommendations for successfully integrating the new Member States' aeronautical research organizations and companies with research capabilities into the relatively well-developed research network of the "older" Member States [39]. As pointed out by a recent report of the European Union about research in the EU-13 countries, despite the efforts made by politics, institutions, and industry, the participation of individual EU-13 countries in European research initiatives is very heterogeneous, but overall, they are underperforming [40]. The results obtained in this paper corroborate that, regardless of the efforts made, there is still a great gap to close for the effective integration of the aeronautical potential research capabilities of the EU-13 countries into the European scheme.
Additionally, the figure not only illustrates higher publication frequencies in both China (Weighted Degree-WD= 1287) and the USA (WD=3217), but also a high level of correlation between their research topics. On the other hand, European countries have very weak connections with the research carried out in China and other Asian economies. Research in the USA plays a pivotal role in the research infrastructure connecting the major players. The elevated number of publications in the USA and China, as well as the highly correlated topics between the two research networks, suggests the need for further analysis of the details of both research networks. Particularly, due to the weak

[1] Group of 13 EU countries: Bulgaria (BG), Croatia (HR), Cyprus (CY), Czech Republic (CZ), Estonia (EE), Hungary (HU), Latvia (LV), Lithuania (LT), Malta (MT), Poland (PL), Romania (RO), Slovakia (SK) and Slovenia (SI)

DOI: 10.13009/EUCASS2019-843

connections between European clusters and Chinese publications, the specific analysis of China's research may provide the insight necessary to develop a competitive EU aerospace innovation policy.

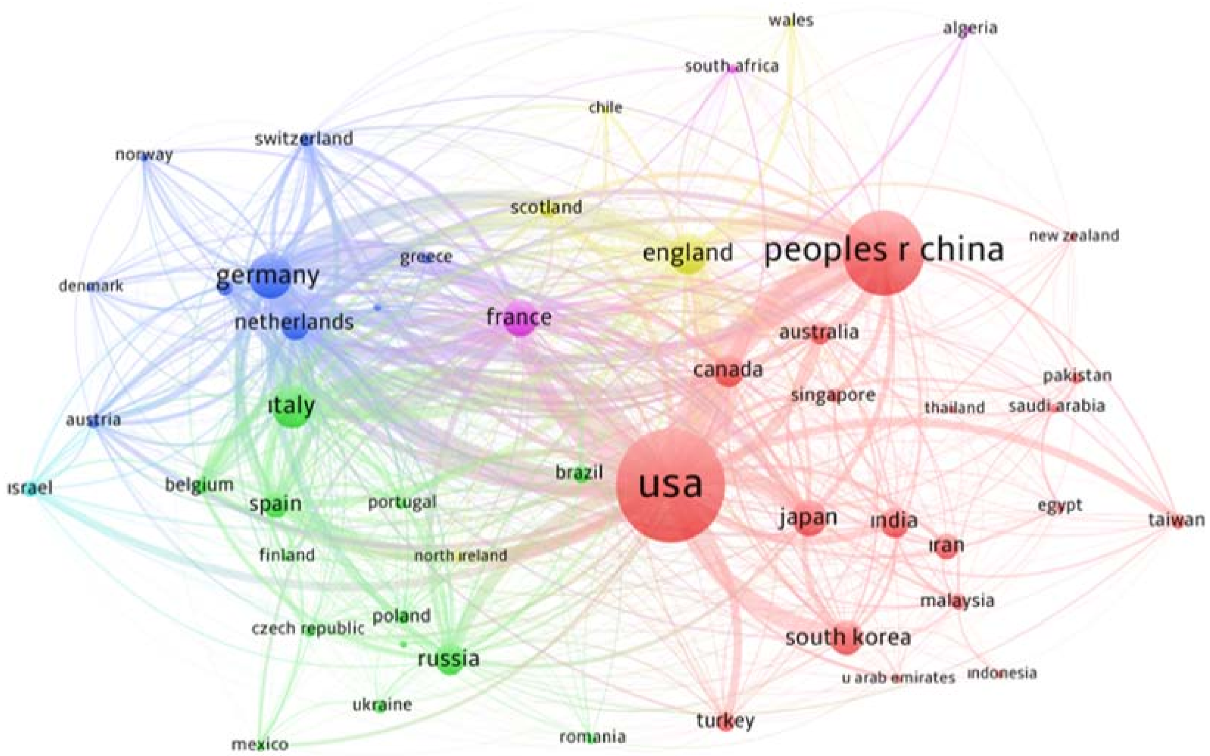

Figure 3. International Collaboration Networks with Document Frequency.

3.2. Collaboration Network of Institutions

A second visualization is prepared to illustrate the institutional collaboration network worldwide. There are many universities and research centers located as illustrated in Figure 4. The European cluster can be identified as the blue group. The figure shows strong links between some Korean universities around the Korea Advanced Institute of Science and Technology that with a WD of 205 is acting as a research enhancer; and some strong links in several USA universities.

Those strong links evidence compact areas of collaboration and integration among these institutions. In particular, it can be observed that universities and research centers in the USA are organized into two distinct clusters. One of them is dominated by NASA (WD=826) and MIT (WD=196), and the other one is shared among NASA, some universities, and the United States Air Force (WT=179). Xiuxiu obtained similar results [41].

The main research directions of the two USA groups are the space station, target tracking, and monitoring of aircraft feedback. USA universities with highest weighted degree are Caltech (WD=485), Georgia Institute of Technology (WD=217), University of Michigan (WD=217), Massachuset Institute of Technology –MIT (WD= 196) and the University of Colorado (WD=184). Among the 10 top institutions we can also find the Japan Aerospace Exploratory Agency (WD= 203), the Korea Advanced Institute of Science and Technology (WD=205) and the Beihang university (WD=150). The 3 of them play a pivotal role agglutinating and connecting research initiatives in their respective countries.

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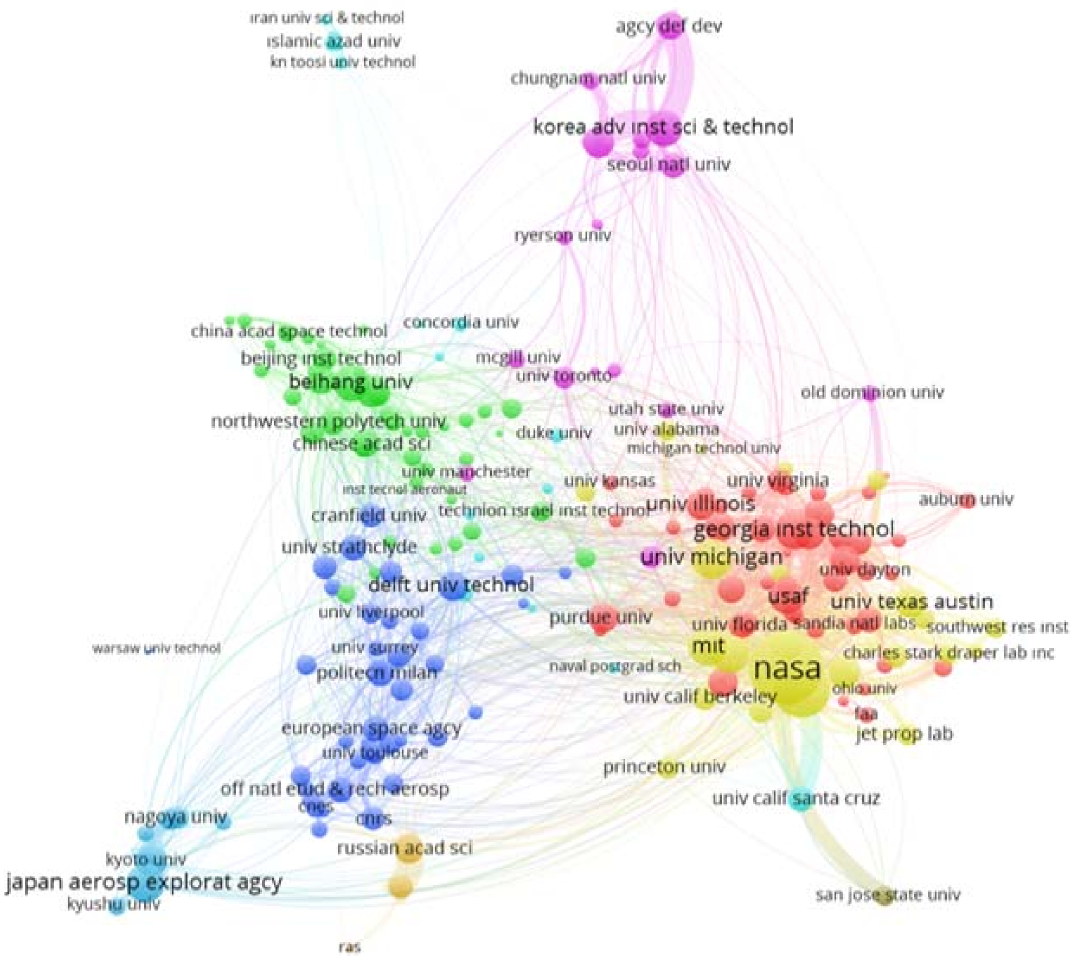

Figure 4. Institutional Collaboration Network. .

3.3. Collaboration Networks in Aerospace Engineering Subfields.

Finally, the last visual is prepared for demonstrating the research space of aerospace engineering by using the co-occurrences of different Web of Science categories. The prepared visual is shown in Figure 5. Naturally, aerospace engineering (WD=40419) is the central node of the network because it was the main Web of Science category selected. Additionally, five main clusters, clsuter in the figure with different colors, are identified that cover the following fields:

- Mechanical engineering (WD=10173), including biomedical engineering (WD=292), robotics (WD=46), and manufacturing (WD=886),
- Physics (WD=187), automation (WD=2020), telecommunications (WD=6798), electric-electronic and computer science (WD=13218);
- Materials science optics (WD=7937), nano-science and remote sensing (WD=3409);
- Energy (WD=1644) and polymer science (WD=263);
- Acoustics (WD=734), thermodynamics (WD=1106), environmental studies (WD=54) and geology (WD=54).

The co-occurrence network graph in Figure 5 illustrates the connectivity among various research topics in the aerospace literature. The size of the nodes reflects the frequency of keywords: the higher the frequency of the keyword, the larger the size of the node. The size of the node also indicates also weighted degrees of the topic. The thickness of the line is proportional to the nearness of keyword connections; the closer the relationship between two nodes, the thicker the line.

Nodes without connections signify research fields lacking substantial cooperation with other research areas in the aerospace literature; they may be considered emerging or nascent topics that are sometimes in the margin of a research field, or they can be identified as areas in which mutual collaboration is lacking.

Mechanical engineering (WD=10713), telecommunications (WD=6798), electrical and electronics engineering (WD=13218), instrumentations (WD=5450), astronomy and astrophysics (WD=4028), optics (WD=7937), mechanics

DOI: 10.13009/EUCASS2019-843

(WD=3864) had the highest frequency of co-occurrence in the literature with aerospace engineering, evidencing the areas were aerospace engineering publications are concentrated.
It is worth comparing the topics in Figure 5 with the 11 areas previously identified (see section 2.1) as key scientific disciplines involved in aircraft development. It can be observed that all of these areas are present in figure 6 with a relatively high number of publications. However, these areas are not highly interconnected, evidenced by the lack of common research, and are thus losing potential synergies that could foster innovation. According to Figure 5, this lack of common research is particularly notable between physics (WD=187), computer science (WD=174), and materials engineering (WD=520)—three fields among which collaboration is required to boost aviation innovation. To close this gap, it will be necessary to promote collaborative studies between these areas as part of the aerospace innovation funding policy.

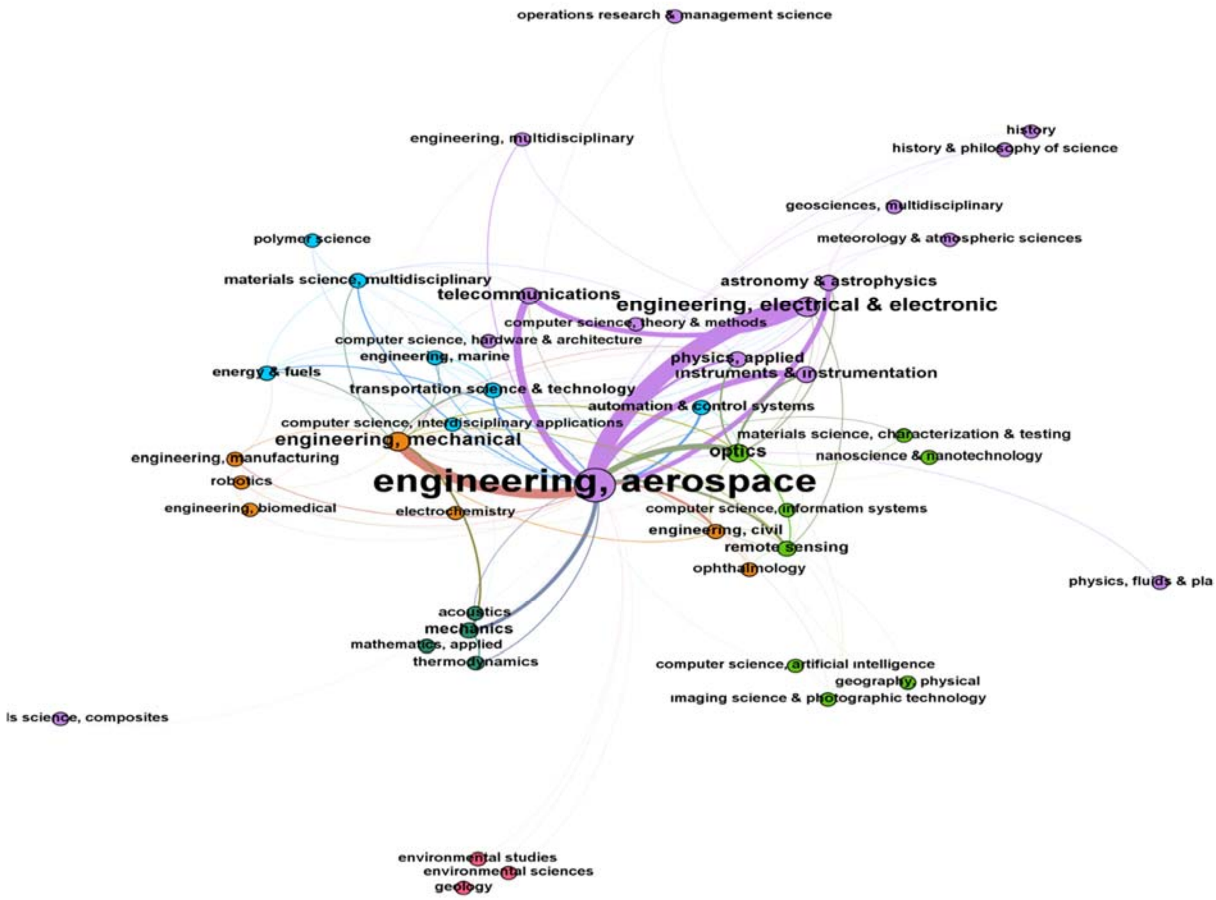

Figure 5. Collaboration Networks Based on Web of Science Categories.

4. Assessment of the European aerospace innovation capacity on the basis of mapping patents in aviation technologies.

The patent analysis performed in this study covers the following topics:

- Analysis of the trends of patents in aviation through the annual distribution analysis,
- Regional distribution analysis of the patents, including assignee analysis,
- Analysis of the patent structure detailing the technical fields in which patents are produced.

4.1. Trends of Patents on Aviation

Figure 7 presents the yearly evolution of the number of patents in aviation in the last 40 years. It can be observed that the number of patents has grown exponentially in the last decade. Figure 8 shows the breakdown of this evolution into the main Derwent categories. It can be observed that the greatest patent growth has taken place in the categories of operations and physics. Operations and physics are named macro-classes. Second in growth, named medium classes, are electricity, mechanical engineering, and chemistry. In contrast, the area of human factors has experienced very low

DOI: 10.13009/EUCASS2019-843

growth, and the area of textiles has experienced practically no growth. Human factors and textiles are grouped in the micro-classes.

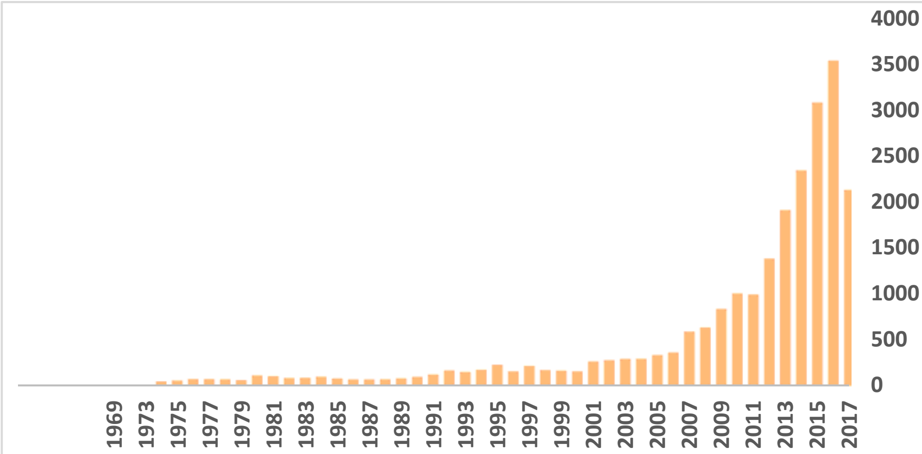

Figure 6. Number of patents in aviation per year.

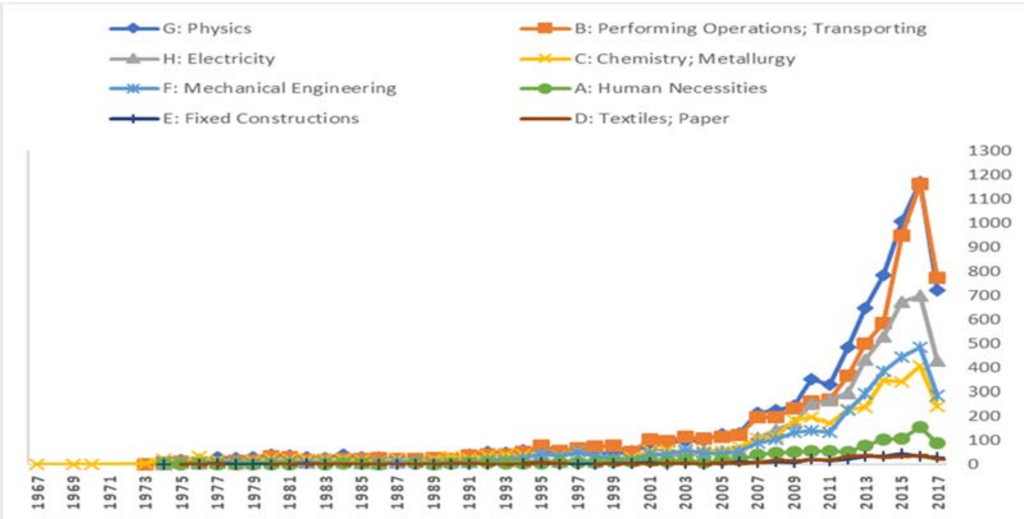

Figure 7. Chart of subclasses per year.

4.2. Geographical analysis.

¡Error! No se encuentra el origen de la referencia. summarizes the accumulated number of patents per country. Figure 8 presents the annual evolution of patents for the top 10 countries, and Figure 9 shows the distribution of the patents according to class for these top 10 countries.

Table 1. Number of patents per country

Basic Patent Country	Patent Number
China	11876
United States of America	3249
Russian Federation	2140
Soviet Union (USSR)	1393
World Intellectual Property Organization (WIPO)	1327
Korea (South)	1308
European Patent Office	637
Germany	369
France	305
Japan	254
United Kingdom	191

DOI: 10.13009/EUCASS2019-843

India	98
Canada	56
Brazil	37
Australia	28
Belgium	28
Taiwan	26
Romania	19
Spain	15
Poland	**14**

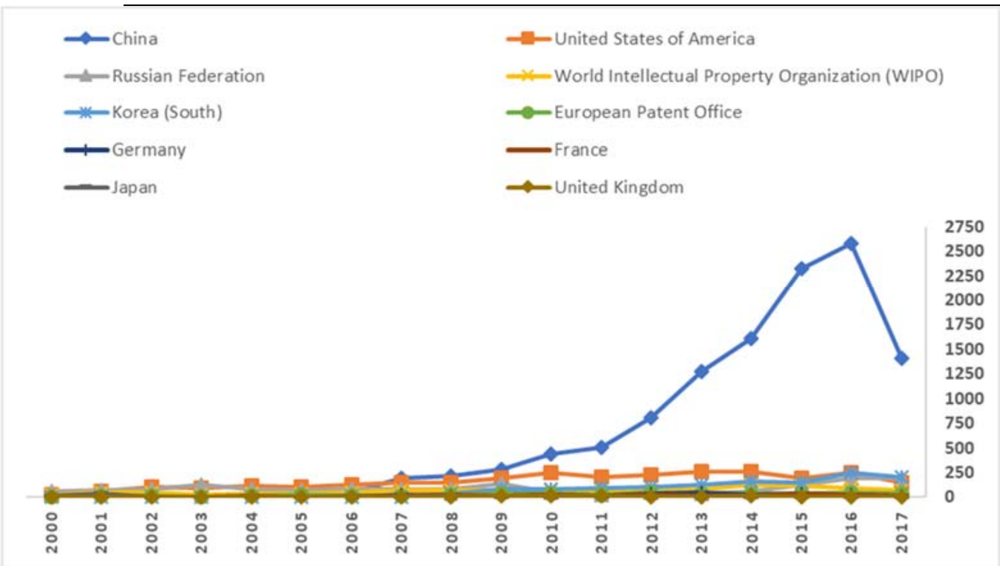

Figure 8. Evolution of the number of patents.

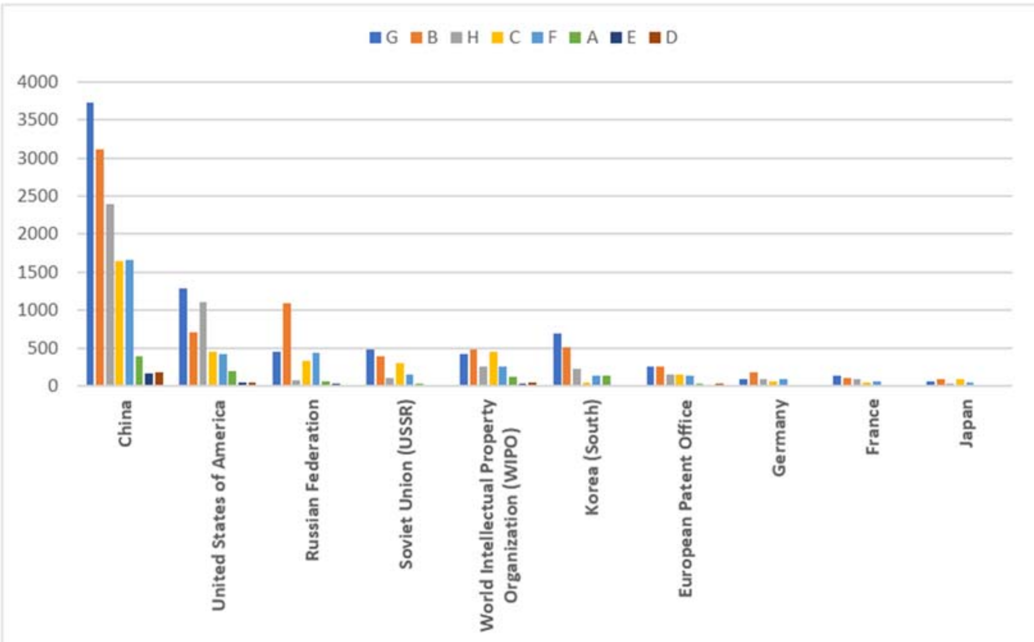

Figure 9. Aviation patents per country and class (A: Human necessities; B: Performing operations and Transporting; C: Chemistry and Metallurgy; D: Textiles and Paper; E: Fixed constructions; F: Mechanical Engineering, lighting, Heating, Weapons, and Blasting; G: Physics; H: Electricity).

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China is observed to be the country with the most patents in aviation, showing a strong dynamic in the field of patenting. There is a sharp increase in the volume of patents filed in China: the number has quadrupled in the last five years. The data reflect how Chinese agents protect their intellectual property through patents, regardless of whether it was received through technology transfers or generated autonomously. Some authors have regarded this situation as replicating the strategy applied by the government and the Chinese industry in the railway sector; that is, the progressive development of barriers that are put in place to reduce the ability of non-Chinese agents to access the domestic market [40].
The high attrition rate should not be considered in isolation, as sometimes it is a consequence of governmental policies and effectively decreases when incentives are no longer applicable. Most authors recommend studying the patent lifecycle and its utility by periodically reviewing the number of patents discarded after a 5- or 10-year period [42], the number of international citations [43], or the citation lag [44].
The geographical analysis is complemented with the analysis of patent assignees. Table 2 summarizes the top 20 firms by patent number. Figure 10 illustrates the evolution of the annual number of patents for the 10 top firms, and Figure presents the number of patent per holder according to subclasses.

Table 2. Top Twenty Firms by number of patents.

Patent Assignees	**Records**
Stats Chippac Ltd	369
Honeywell Int Inc	233
Shenyang Liming Aero Engine Group Corp	222
General Electric Co	193
Univ Beijing Aeronautics & Astronautics	189
Univ Nanjing Aeronautics & Astronautics	165
Boeing Co	151
Harbin Inst Technology	145
State Grid Corp China	142
Rockwell Collins Inc	123
Univ Beihang	106
Avic Comml Aircraft Engine Co Ltd	103
Aviation Ind Corp China Shenyang Engine	99
Stats Chippac Pte Ltd	94
Univ Northwestern Polytechnical	90
Aviation Materials Res Inst	88
Univ China Civil Aviation	83
Thales	75
Avic Shenyang Engine Design Inst	71
United Technologies Corp	71

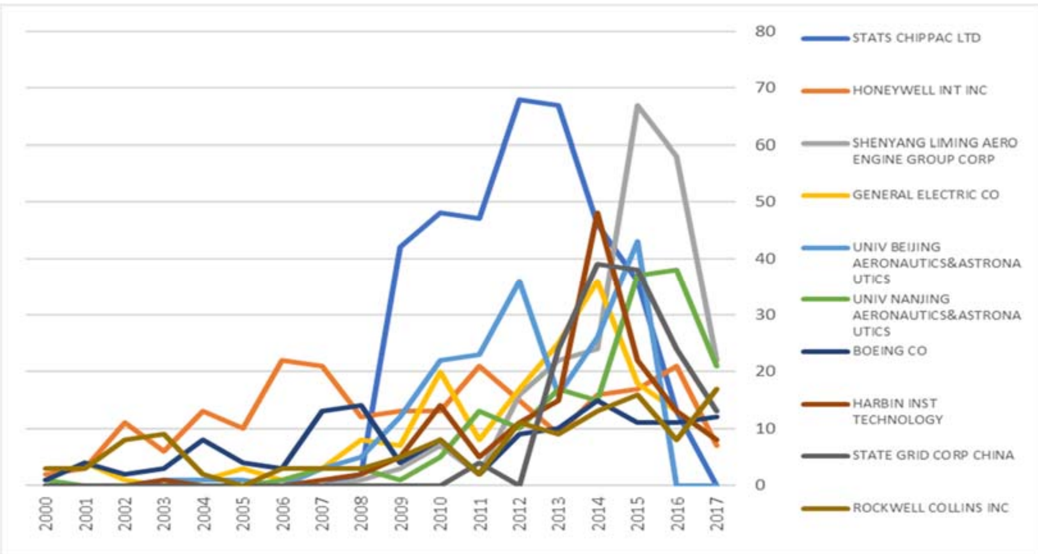

Figure 10. Top Ten Firms by number of patents.

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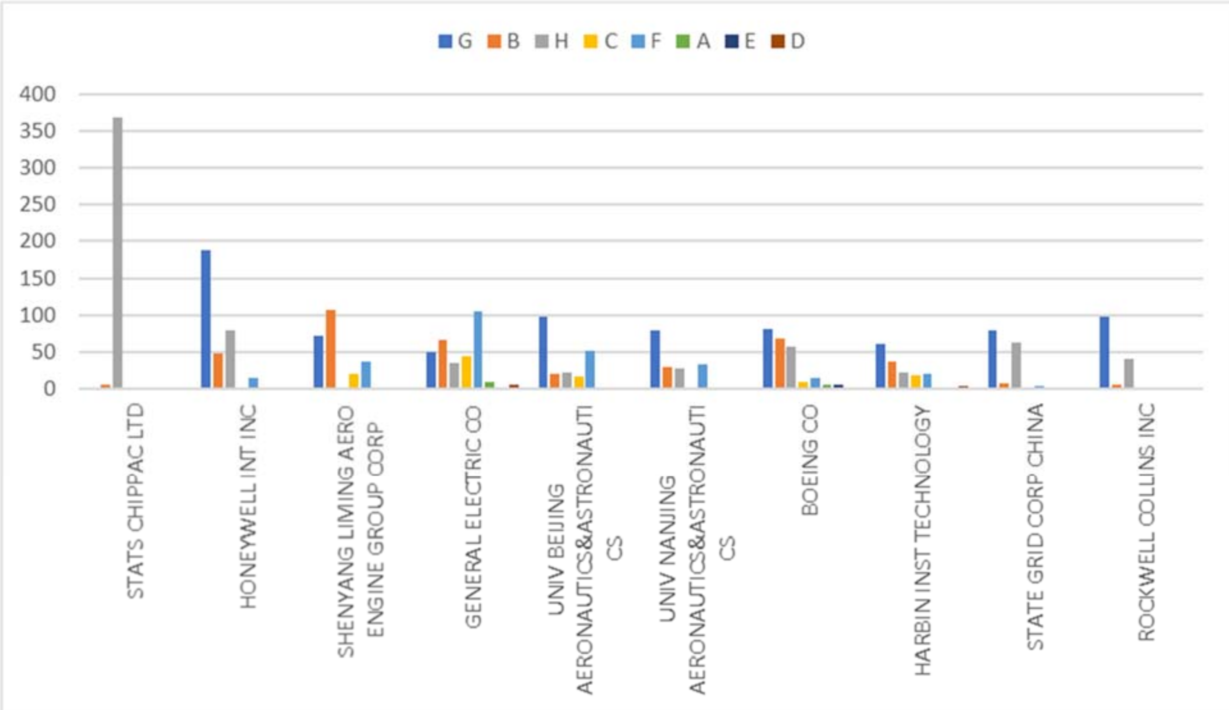

Figure 12. Number of patents per holder.

The above results show that although there was significant dominance by universities and research centers worldwide in the publication network (see section 3.1.2), there are only a few universities among the top 20 firms by number of patents, and all of them are Chinese universities. This highlights the lack of capacity of universities in Europe, as well as the USA, to translate basic research into products and industrial innovation. Future innovation and research policies should contribute to closing the existing research and innovation gap between academia and the aeronautical industry. University spin-offs may be integral to bridging this gap by playing different roles in intermediation, technology diversification, and technology renewal [45]. University spin-offs are start-up companies that are created by academics to exploit technologies and knowledge originating from the university. During the last two decades, spin-offs from universities have attracted increasing interest from research institutions and industry, mainly because these spin-offs have the capacity to bridge the gap between scientific and academic knowledge and their industrial application [45] [46]: “Universities need to reinvent themselves as micro environments for innovation and entrepreneurship. A university that will not demonstrate its impact on industry and the marketplace will become less relevant in the future” [46]. Today, Israel is the country with the most efficient policies for transferring innovation from universities and military tech units to industry and production. Policy programs are needed to stimulate entrepreneurial activities of academics in aerospace [47].

The last conclusion, which is derived from the above analysis, is regarding the specific geographical differences between aerospace science and technology journals and patent information. Only one among the 20 top firms is European (Thales), and the remaining companies are American or Chinese. It is also remarkable that Airbus Industries is not among the top firms by number of patents.

4.3. Patent structure analysis.

In this section, we examine the technological network derived from the patent technology space. Table 3Table 3 represents the percentages of patents for each class, and Table 4 and **¡Error! No se encuentra el origen de la referencia.** present the percentages for each subclass in the categories of physics and operations. As can be observed in Table 3, among the aviation patents, about 27% belong to the class of Physics, and 25% are in the class of Operations and Transporting. Table 4 and **¡Error! No se encuentra el origen de la referencia.** show the areas with higher concentrations of patents among the subclasses in Operations and Physics. **¡Error! No se encuentra el origen de la referencia.** presents a classical sunburst diagram for general macro-classes and their subclasses.

Figure 113 presents a network map of the patent topics relevant to aviation development. Five major clusters are observed in the figure with very limited interconnections. One cluster aggregates classes around power generation topics, including electronics and materials involved in power systems. Another integrates instrumentation, digital computers, optics, printed circuits, and semiconductor materials and processes. The third one pivots around all types

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of materials used for aviation. The fourth includes electromechanical storage, power distribution, components, converters, and lighting. The last one includes organic compounds, lubricants, etc. It can be seen that, aside from the differences in the names of the classes, there is a high level of correlation between the areas in which patents and publications are produced.

The next step consists of comparing the network structures derived from the analysis of publications (Figure 5) and from the analysis of patents (Figure 11). This figure shows that whereas a high level of cooperation and a mature stage is seen at the level of publication networks, the patent cooperation networks are relatively low and primary. It can also be seen that there are significant differences in the density between the two networks. The network structure derived from publications presents a lower density exhibiting higher and looser contact, whereas the patent network is denser with less contact between the nodes and a closer structure. Worldwide universities are well represented in the publication networks, while the patent network is dominated by companies, apart from Chinese universities. It is believed that cooperation should be aimed at the differences to encourage the integration of academic research and applied research so as to promote the development of the subject and the level of aerospace industry.

Table 3 . Some patent codes.

Code	**%**	**Definition**
G	27.3	Physics
B	24.9	Performing Operations; transporting
H	16.2	Electricity
C	13.1	Chemistry; Metallurgy
F	12.2	Mechanical Engineering; lighting; Heating; Weapons; Blasting
A	3.7	Human Necessities
E	1.3	Fixed Constructions
D	1.3	Textiles; Paper

Table 4. Some patent subcodes.

Code	**%**	**Definition**
G01	12.7	Measuring; Testing
B64	9.3	Aircraft; Aviation; Cosmonautics
H01	6.2	Basic Electric Elements
G06	6.2	Computing; Calculating; Counting
H04	4.0	Electric Communication Technique
C08	3.1	Organic Macromolecular Compounds; Their Preparation Or Chemical Working-Up; Compositions Based Thereon
C10	3.1	Petroleum, Gas Or Coke Industries; Technical Gases Containing Carbon Monoxide; Fuels; Lubricants; Peat
F16	2.9	Engineering Elements Or Units; General Measures For Producing And Maintaining Effective Functioning Of Machines Or Installations; Thermal Insulation In General
F02	2.9	Combustion Engines; Hot-Gas Or Combustion-Product Engine Plants
H02	2.8	Generation, Conversion, Or Distribution Of Electric Power
B23	2.6	Machine Tools; Metal-Working Not Otherwise Provided For
G05	2.5	Controlling; Regulating
G08	2.0	Signaling
G09	1.9	Educating; Cryptography; Display; Advertising; Seals
C22	1.7	Metallurgy; Ferrous Or Non-Ferrous Alloys; Treatment Of Alloys Or Non-Ferrous Metals

Table 5. Some patent sub-subcodes.

Code	**%**	**Definition**
B64C	4.1	Aeroplanes; Helicopters
B64D	3.7	Equipment For Fitting In Or To Aircraft; Flying Suits; Parachutes; Arrangements Or Mounting Of Power Plants Or Propulsion Transmissions
G06F	3.7	Electric Digital Data Processing

DOI: 10.13009/EUCASS2019-843

G01N	2.2	Investigating Or Analysing Materials By Determining Their Chemical Or Physical Properties
G01C	1.9	Measuring Distances, Levels Or Bearings; Surveying; Navigation; Gyroscopic Instruments; Photogrammetry Or Videogrammetry
G01M	1.8	Testing Static Or Dynamic Balance Of Machines Or Structures; Testing Structures Or Apparatus Not Otherwise Provided For
C08L	1.7	Compositions Of Macromolecular Compounds
H01L	1.7	Semiconductor Devices; Electric Solid State Devices Not Otherwise Provided For
G01R	1.4	Measuring Electric Variables; Measuring Magnetic Variables
B32B	1.4	Layered Products, I.E. Products Built-Up Of Strata Of Flat Or Non-Flat, E.G. Cellular Or Honeycomb, Form

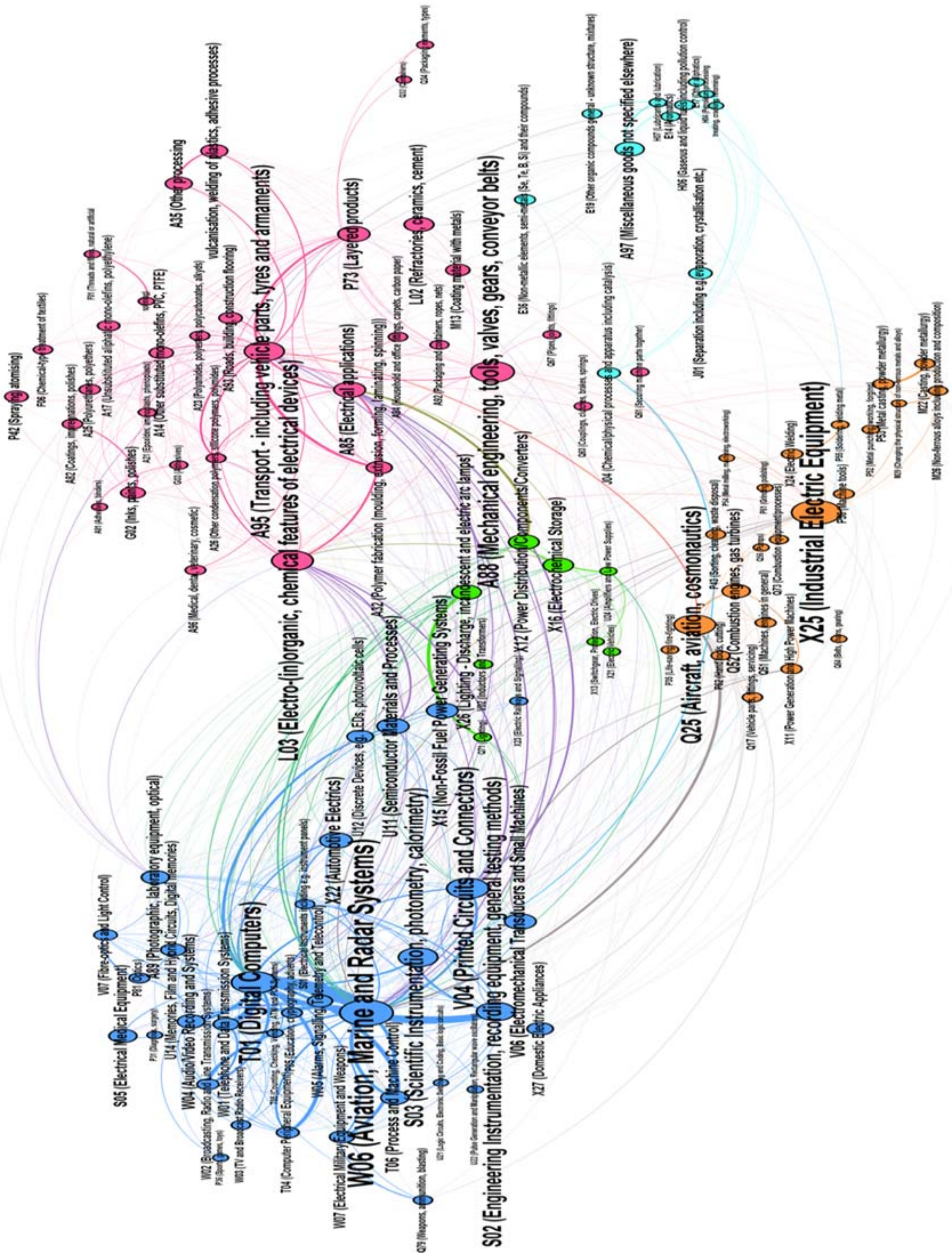

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Figure 11. Patents in areas relevant to aeronautics.

4. Conclusions and recommendations

To cope with the challenges and opportunities that populate the 2050 horizon, the aviation industry needs to maintain its technological innovation capability. To achieve the required level of innovation across the full range of aeronautical products, it will be necessary to (a) master leading-edge technologies in all sectors that contribute to the design of aeronautical vehicles; and (b) collaborate to integrate all of these cutting-edge technologies into efficient aircraft production, certification, and service support programs.

In this paper, we present the research accomplished by the PARE project to assess the potential for future long-term technological innovation. This assessment was performed through the characterization of a map of the Aviation Technology Space and provides hindsight into two complementary issues: (a) the capacity of the industry to master key technological areas and to innovate within them; and (b) the aerospace collaboration structures and their ability to cooperate effectively and aggregate knowledge and efforts into the innovation path.

On one side, on the basis of the keyword co-occurrence analysis method, we performed a bibliometric network analysis of more than 58,000 aviation research scientific publications available from Web of Science to map the aerospace collaboration structures. Complementarily, we performed an analysis of more than 23,000 aviation patents to evaluate the innovation capacity of the industry in the cutting-edge technologies previously identified.

The analysis demonstrates and identifies the existence of international scientific collaboration networks. Its structure of clusters highlights how the technological capabilities in aerospace engineering are spread or concentrated. The study highlighted not only higher publication frequencies in both China and the USA, but also a high level of correlation between their research topics. It can be observed that in Europe, research capabilities and knowledge are homogeneously spread with a clear geographical correlation into four highly specialized clusters. Additionally, the results presented in this paper corroborate that, regardless of the efforts made, there is still a great gap to close for the effective integration of the EU-13[2] countries' aeronautical potential research capabilities into the European scheme.

To maintain foster innovation, aviation research policy should support a view that every cluster can continue gaining excellence in different subfields. At the same time, research policy must facilitate the aggregation of the dispersed experience and knowledge in each subfield into a shared platform for the aviation industry. Particularly, in light of the weak connections between European clusters, the United States clusters, and China's publications, a specific analysis of China's research may provide the insight needed to develop a competitive aerospace innovation policy in other regions.

The analysis also allows for identifying the current main aerospace subfields of research within this international scientific collaboration network. By using the co-occurrences of different Web of Science categories, five main clusters are identified covering the following fields:

- Mechanical engineering, including biomedical engineering, robotics, and manufacturing,
- Physics, automation, telecommunications, electric-electronics, and computer science,
- Materials science optics, nanoscience, and remote sensing,
- Energy and polymer science,
- Acoustics, thermodynamics, environmental studies, and geology.

Mechanical engineering, telecommunications, electrical and electronics engineering, instrumentations, astronomy and astrophysics, optics, and mechanics have the highest frequency of co-occurrence with aerospace engineering in the literature, evidencing the areas in which aerospace engineering publications are concentrated. However, these areas are not highly interconnected, evidencing a lack of common research, thus losing potential synergies that could foster innovation. This lack of common research is particularly evident between physics, computer science, and material engineering. These are three fields in which collaboration is required to boost aviation innovation. To fill this gap, it will be necessary to promote collaborative studies between these areas as part of the aerospace innovation funding policy.

The greatest patent growth has taken place in the categories of operations and physics. Second in growth, named medium classes, are electricity, mechanical engineering, and chemistry. In contrast, the area of human factors has experienced very low growth, and the area of textiles has experienced practically no growth.

It is clear from the results that China is the country with the highest number of patents in aviation. Another conclusion derived from the above analysis is that specific geographical differences exist between aerospace science and technology journals and patent information. Only one among the 20 top firms is European (Thales), and the remaining companies are American or Chinese. It is also remarkable that Airbus is not among the top firms by number of patents.

[2] The group of 13 EU countries includes: Bulgaria (BG), Croatia (HR), Cyprus (CY), Czech Republic (CZ), Estonia (EE), Hungary (HU), Latvia (LV), Lithuania (LT), Malta (MT), Poland (PL), Romania (RO), Slovakia (SK) and Slovenia (SI)

DOI: 10.13009/EUCASS2019-843

A network map of the patent topics relevant to aviation development shows 5 major clusters with very limited interconnections. Apart from the differences in the names of the classes, there is a high level of correlation between the areas in which patents and publications are produced.
The global institutional collaboration network shows that while there is a significant dominance of universities and research centers worldwide in the publication network, there are only a few universities among the top 20 firms by number of patents, and all of them are Chinese universities. This highlights the lack of capacity of universities in Europe, as well as in the USA, to translate basic research into products and industrial innovation. Future innovation and research policies should contribute to closing the existing research and innovation gap between academia and the aeronautical industry to encourage the integration of academic research and applied research so as to promote the development of the subject and the level of aerospace industry.
This study has some limitations that should be overcome in future studies. A deeper merging of publication data and patents could be achieved by completing this analysis with patent citations, particularly the unification of inventor and author names, as well as patent to patent citations. This will allow for the analysis of the quality of the patents. The analysis should be repeated periodically to verify the advancement of research and innovation toward the goals of aviation in 2050. Additionally, further studies should look in more detail to whether current research and innovation will actually be capable of addressing the challenges of the future. An analysis of the level of maturity of the research reflected in patents and publications, as well a more detailed technological coverage map could be developed to address this last topic.

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