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Emerging Technologies in European Aeronautics: How Collaborative Innovation Efforts are Shaping the Industry

Nikola Radovanovic, Petros Gkotsis, Mathieu Doussineau

Abstract**—**Aeronautics is regarded as a strategically important sector for European competitiveness. It was at the heart of European entrepreneurial development since the industry was born. Currently, the EU is the world leader in the production of civil aircraft, including helicopters, aircraft engines, parts, and components. It is recording a surplus in trade relating to aerospace products, which are exported all over the globe. Also, this industry shows above-average investments in research and development, as demonstrated in the patent activity in this area. The post-pandemic recovery of the industry will partly depend on the possibilities to streamline collaboration in further research and innovation activities. Aeronautics features as one of the often-selected priority domains in smart specialisation, which represents the main regional and national approach in developing and implementing innovation policies in Europe. The basis for the selection of priority domains for smart specialisation lies in the mapping of innovative potential, with research and patent activities being among the key elements of this analysis. This research is aimed at identifying characteristics of the trends in research and patent activities in the regions and countries that base their competitiveness on the aeronautics sector. It is also aimed at determining the scope and patterns of collaborations in aeronautics between innovators from the European regions, focusing on revealing new technology areas that emerge from these collaborations. For this purpose, we developed a methodology based on desk research and the analysis of the PATSTAT patent database as well as the databases of R&I framework programmes.

Keywords**—**aeronautics, smart specialisation, innovation policy, regional policy.

Classification Codes**—**O32, L62, L93, R58.

I. Introduction

AERONAUTICS is one of the crucial high-tech sectors for the EU and represents a key asset for its future. Its high technology nature and vigorous orientation to innovation profile give direct impetus to European pioneering of the desired knowledge society. The tendency of the European Union to build strong research and innovation profile in high-technology industries is strongly upheld by its dedicated research efforts in the area of aeronautics. The stronghold of this industry in the EU is well represented by the trade surplus that the EU records for aerospace products and employment and turnover numbers, as the industry provides 405000 jobs, generates €130 billion revenues and plays a leading role in exports, amounting to €109 billion (in 2019) [38]. Prioritising aeronautics among advanced technology sectors is crucial for European competitiveness as it drives further innovation efforts, whilst technology developments in this area also can instigate spillovers into other areas.

The sector of aeronautics functions under specific circumstances in terms of innovation. The innovation in aeronautics is complex and capital-intensive, and based on very long lead times. Since the birth of aeronautics, patents have been important strategic and commercial instrument. Nowadays, patent activity in aeronautics has been increasing, fuelled by incentives from national or corporate programmes, rapid technology development and maturing markets. Patents are becoming more important for growing SMEs, mid-caps and large organisations. As the maturity of technologies intensifies competition between companies, they tend to increase their patents to secure more incremental innovations and block competitors [1]. The abundance of patents makes the industry ripe for innovation. It should be noted that national laws requiring that sensitive information is not revealed often hamper patent activity in the aerospace industry. Some companies tend to choose secrecy over patenting due to possibly longer protection. However, the need for standardisation of the industry due to safety requirements requires that innovations comply with various regulations, which emphasises the patenting route.

Europe is spending substantial financial resources on research and development (R&D) in aeronautics, which is reflected in an increasing number of patent applications. The spending on R&D is on the level of 10% of industry turnover [2]. The share of R&D investments in 2019 for aerospace and defence in the EU stood at 4.3%, while the same indicator was at 2.4% for the USA and at 0.4% for China, with negligible levels for Japan. However, due to the global economic crisis caused by the COVID-19 pandemic, these levels recorded decline in 2020 to 3.4% for EU, 1.9% for the USA and 0.3% for China. At the same time, the EU's contribution of the aerospace and defence sector's R&D at the global level recorded slight decline from 40% in 2019 to 38.9% in 2020 [3], [4]. The aerospace and defence sector is strategically important in terms of market potential, as the best sales performance of EU companies when industries are considered comes from this

Nikola Radovanovic*, Petros Gkotsis, and Mathieu Doussineau are with European Commission, Joint Research Centre, Spain (*corresponding author; e-mail: Nikola.RADOVANOVIC@ec.europa.eu).

sector. Several initiatives have been created for the goal of utilising and enhancing European potential in aeronautics. One of them is the Advisory Council for Aeronautics Research in Europe (ACARE) with the Strategic Research and Innovation Agenda (SRIA), which includes a roadmap developed by the European industry providing a guide to future public and private RDI programmes. The SRIA is focused on meeting the challenging goals set by the Flightpath 2050 roadmap [5], which gave a long-term vision for the European aeronautics sector. Under the objective of industrial leadership, the goals of Flightpath 2050 are to maintain leading-edge design, manufacturing and system integration capabilities and jobs supported by high profile, strategic, flagship projects and programmes. The roadmap covers the whole innovation process from basic research to full-scale demonstrators. Having European research and innovation strategies jointly defined by all stakeholders and implemented in a coordinated way covering the entire innovation chain is yet another goal of the Flightpath 2050 to prioritise research, testing capabilities, and education. Important initiatives in the area of aeronautics research are also the two Joint Undertaking Clean Sky and SESAR and the Aeronautics & Aerospace European Platform. Funded by the EU Horizon 2020 programme, Clean Sky contributes to strengthening European aero-industry collaboration, global leadership, and competitiveness. SESAR, as part of the Single European Sky (SES) initiative, represents the mechanism for coordinating R&D activities in air traffic management (ATM). The Aeronautics & Aerospace European Platform deals with aerospace engineering and puts together individuals and organisations from Europe who wish to conduct research, development and application of technologies in aeronautics and astronautics.

The vision for 2020 entailed that the way forward for the sector was to encourage the creation of partnerships for research and innovation. Key goals under such vision were to develop new synergies between EU, national and regional research programmes, and minimise unnecessary research duplication [6]. In general, the sector is characterised by global dynamics and proneness to forming alliances and partnerships under the objective of competitiveness. At the same time, collaboration is constrained by competitiveness rather than geography, which is why European companies need to strive towards excellence to forge the best possible partnerships. In this sense, the cooperation perspective among EU countries is enhanced by high geographical concentration of large businesses (Airbus, one of the leading global manufacturers in aeronautics, is a good example of that) representing high employment share in European leading regions.

Aeronautics is one of the industries that suffered a heavy blow from the COVID-19 repercussions, mostly due to the collapse of the demand for travel. The recovery is facing multiple challenges, among which are the behaviour of passengers, restrictive actions on travel by governments, as well as global economic downturn [7]. Most authors agree that it will take several years to bring the air traffic level to the one before the COVID-19 crisis, see [16], and [17].

Innovation will play a crucial role in the industry recovery. In this regard, efforts are foreseen to be focused on certain innovation areas, such as health and safety measures, new systems and tools, as well as environmentally sustainable solutions. Companies would need to review product and innovation strategies in light of changed market needs. Understanding where in the wide field of aeronautics cooperation occurs and identifying innovation areas where potential partners operate would help them redesign strategies. In the new industry setup, the need to uniting research and innovation efforts will be highly demonstrated.

The smart specialisation process can optimise the use of innovation potential for economic growth. It can streamline research and innovation policies on both regional and national levels by focusing on identifying promising areas for specialisation where further investments would yield optimal results. By revealing such priority areas, it helps in locating potential for collaboration between the regions or countries to extract the best value and enhance value chains. Key features of the smart specialisation approach are evidence-based analyses of economic, innovation and scientific potential combined with continuous discussion of all relevant stakeholders on priority domains. The ability to alert on the emerging research areas for advancing European competitiveness puts smart specialisation among key processes that can help Europe to establish itself as a globally competitive knowledge-based continent.

Building on the abovementioned, our aim was to analyse the scope of collaborative innovation ventures in the field of aeronautics in Europe, as well as to map these collaborations at a regional level and technological level. The analysis included identifying key cooperating regions within Europe and the technological directions of their collaboration. It covered the period between 2008 and 2018. The analysis of the scope of innovation collaboration between EU regions and emerging technology areas in aeronautics was also aiming at demonstrating if the regions that designated aeronautics as their S3 priority are more active in cooperation and widening of the technology areas than the regions that did not. In that way, the research aims at confirming the direct link between designated S3 priority domain and increased innovation efforts in that domain. For the analysis, we used patent database as well as the database on research and innovation framework programmes as primary sources, while consulting available literature to complement the research efforts.

The following chapters of the document include literature review, methodology, data analysis, results and conclusion.

II. Literature Review

As a rapidly developing industry, the nature of the aeronautics sector was of an integrational character, as its evolution often required cooperation efforts beyond country borders. This was particularly demonstrated on the European continent. The globalisation and unique single market increased the need for using air travel for everyday activities in the continent, therefore driving the development of the industry in Europe. Radwan [8] suggests that aeronautics and aerospace pioneered European integration after the two world wars. The cooperation efforts of the European leaders since the first steps towards a reinforced European political integration have sparked the rapid growth of the aerospace industry, making it highly competitive on the global market. A genuine example of this cooperation is the creation of Airbus, which, for many decades now, employs workers from many European countries. The growth of the European industry by the end of the last century can also be attributed to the industry's reaction to the consolidation of the US competitors [9]. Nowadays, the European aviation market is highly dynamic, which further drives the sector's development, including manufacturers, companies operating in the aviation market and airport offerings [10].

Rapid development of the industry can be also partly attributed to the evolution of the computer-based tools. In particular, this phenomenon led to increased simulation options and decreased physical tests in many technological areas within the sector, providing higher efficiency with considerably fewer physical resources employed [11]. Ceruti et al. [12] argue that the Industry 4.0 would have a disruptive effect on certain fields of aeronautics, such as aircraft maintenance. The authors suggest that additive manufacturing and augmented reality, as boosted by the Industry 4.0 revolution, would likely drive development of future aircraft maintenance strategies. We can also anticipate that the urgent need to address the long-term environmental damage caused by the development of aviation industry should affect the patenting patterns (e.g., electric systems, hydrogen propulsion, new materials).

The European aeronautical engineering sector is characterised by a high level of interaction between the various actors, with their relationship being significant to the network. The networks often demonstrate a competitive nature as firms take competition into account at all value chain steps [13]. Monroy and Arto [14] argue that the industry is turning to the convergence between using global manufacturing virtual networks and mass customisation systems and to even greater "virtualisation" of the networks. According to these researchers, this will depend on the product modularity aspect (i.e., the ability to combine different components based on client's wish) and superficial changes to the aircrafts (i.e., many configuration options) in response to market needs. The importance of value chains in aeronautics grows with the impact of COVID-19 on the industry, as it is expected that the companies operating in the aeronautics sector will have to rethink or redefine their value chains for sustainable recovery [7]. Hader [15] suggests that the need to collaborate in the post-COVID world will be as strong as ever, positively affecting new business arrangements. Companies and governments are expected to intensify cooperation to save the industry, while the efforts would be directed towards creating joint plans to transform the sector.

It is expected that the role of innovation is likely to be increased in the coming years. Innovation efforts will be even more directed towards preserving health and safety of passengers, who are likely to demand new measures to ensure their health and safety inside the aircraft cabin [16]. Some companies (e.g., Embraer) are already looking into health and safety-related innovations to combat the effects of COVID-19. Skibsted [17] assessed that design innovation could play an important part in the sector's recovery. Some of the expected changes include refocusing the innovation efforts on creating new systems and tools to meet sustainability and environmental principles. At the same time, the investments should be directed toward new climate-friendly innovations.

Patents are one of the key drivers for international competitiveness in terms of export growth. New products tend to dominate or even standardise the markets, therefore contributing to the rise in exports. The positive correlation between patenting activity and economic success in international markets was identified by various studies [18]-[25]. As outputs of the R&D processes, patents are expected to be strongly related to countries' export performance [25]. The same authors argued that the increase of one percent in patent applications in a specific technology area can raise by 12.2% the country's exports in that area the following year. The authors pointed out that the causal relationship between patenting activities and exports can be twofold: a patent can impact the export growth and it can also generate new patent applications. The aerospace industry values innovation [26], therefore making patents important ingredient of the innovation landscape. Concerning protection mechanisms and return on innovations, patents lag behind secrecy and lead time in the majority of the manufacturing industries [27]. In a study of appropriability mechanisms employed in the US manufacturing firms for both product and process innovations, aerospace appeared to favour trade secrets and lead time more than patents [29]. Hamdan-Livramento [28] argues that nowadays, with the increasingly specialised nature of the innovation system in aeronautics, the industry appears to be less reliant on the patent processing. Another factor affecting patenting activity is the power to purchase external innovation, which is manifested in this sector. According to James Albaugh [11], Executive Vice-President of Boeing, there is a tendency to purchase innovative small companies instead to expand innovation efforts by the companies themselves. Figures show that there was a global surge in patent applications in aerospace and defence in the period between 2006 and 2015. The main reasons for patenting can be the abundance of safety requirements and regulations asking innovations for compliance, the continuous sharp growth of the industry, and the increasing tendency to patent, making the industry ripe for innovation [29].

The European Commission has introduced aeronautics in its R&D 2nd Framework Programme (FP) in 1989. Directions for the research in the aeronautical field in Europe were influenced by the European Commission's vision. The initiative "European Aeronautics – a Vision for 2020" was one example of this. This was the basis for the ACARE Strategic Research Agendas which, to a certain extent, drove the research and innovation effort in aerospace industry through aligning objectives of state-funded research and university projects in EU member states and through its role in selection of collaborative EC-funded Framework projects [26]. In 2001, gathering 40 members mainly from the industry, ACARE was created to improve the competitiveness of the European Union in the aeronautics field. Since the FP6 (2002-2006), research and innovation programmes have been prepared and proposed by the European Commission with the support of ACARE and then adopted via a co-decision procedure involving the Council and the European Parliament. The FP7 (2007-2013) and the Horizon 2020 programme (2014-2020) proposed a significant increase in the annual budget with more than €250M operated by the European Commission for collaborative R&I projects. The already mentioned two joint undertakings Cleansky and SESAR are crucial for the efforts made by the EU to support the sector with significant budgets (EC contribution for Cleansky initiative was €800M in the 2014-2020 period and €585M for SESAR in the same period). Emergence of aeronautics as one of the most important industries in the EU also led to the initiative Air Transport Net, which is focused on strengthening R&D in the industry through creating opportunities for collaboration between various stakeholders and tackling financial or technical constraints for R&D efforts. The consortium under this initiative included institutions from nine EU member states.

Smart Specialisation represents a concept aiming at the most effective exploitation of regional growth possibilities built around existing place-based capabilities. It defines the virtuous process of diversification by concentrating resources and capacities in a limited number of domains that represent possible paths of transformation of the regional productive structures [30]-[33]. It is focused on boosting regional and national competitiveness by focusing on economic, innovation and scientific strengths. Smart Specialisation concept has become a powerful instrument for place-based innovation-driven growth, and it has been embraced as a key determinant for investments in research and innovation in the framework of the EU regional policy [34], [35]. The concept is attributed to the European Commission's High-Level Expert Group "Knowledge for Growth" [33]. It represents a place-based approach focused on identifying strategic areas for intervention based on the analysis of the strengths and potential of the economy and a broad and comprehensive stakeholder dialogue. In that regard, businesses, public administration, higher education institutions and civil society are put together to discuss the design and implementation of the smart specialisation strategy from the mapping of regional economic and innovation capacities.

By applying analytical and evidence-based methodologies, Smart Specialisation can uncover real potential for economic development, research and innovation and aims at investing in a limited set of carefully chosen priorities, where the potential impact is the highest. As an innovative, place-based approach to innovation, Smart Specialisation became fully adaptable to any national or regional context and fostered economic transformation in all parts of the world. At a global level, the specialisation process also contributes to the achievement of the United Nations Sustainable Development Goals (SDG) with a capacity to drive the promotion of sustainable growth models.

Since 2014, Smart Specialisation has become one of the main drivers for funding research and innovation in Europe. The development of knowledge-based economy was one of the main objectives of the Europe 2020 strategy [36] and the Smart Specialisation process became essential for long-term strategic development of Europe. Its ability to streamline transnational collaboration and participation in global value chains positively affects economic growth [34]. As the aeronautics industry has a strong potential for Europe's competitiveness, which is demonstrated by the orientation of major European economies to increase research activities in this area, it became one of the crucial target domains for smart specialisation in the continent.

III. Methodology

As the first step, we identified regions where aeronautics and aerospace were chosen as specialisation priority. The source of this analysis is the online database Eye@RIS3 hosted by the Smart Specialisation platform of the Joint Research Centre. As of 2021, a total of 32 EU regions chose aeronautics (including aerospace) as priority domain or as a part of wider priority domain.

The next goal was to analyse the categories of patent applications from European regions and distinguish the groups of regions that have aeronautics as S3 priority. The retrieved sample covered all patent applications, including the class B64 (and its subclasses) of the International Patent Classification (IPC) which refers to the subjects of aircrafts, aviation and cosmonautics. The information retrieved also included inventor data as the source of the analysis of cooperation on the application between the regions in Europe. The sample was then filtered by eliminating the class B64 and all relevant subclasses within that class so that the remaining subclasses could provide results on the possible emerging technology areas used in the applications covering the aeronautics area. In total, 347 unique patent applications were analysed in this step. Based on the inventor data, from the patent applications, we have retrieved information about the NUTS2 level regions for each country. These data served as the basis for analysing the extent of cooperation between inventors from different countries in Europe, aiming to identify the spectre of cooperation areas.

In order to validate the results, we have conducted the analysis of the research framework programme Horizon 2020 and cross-examined the findings from both PATSTAT and R&I framework programme databases. A total of 624 (H2020) and 487 (FP7) research projects in aeronautics have been analysed. Projects proposals were submitted by consortia of public and private entities that are active in research, such as universities, research centres, industrial partners. Proposals were submitted in response to calls for proposals which are periodically published by funding agencies.

For identifying technology clusters common among patents and framework programme projects, we applied a hierarchical clustering methodology to diversify key clusters of patent applications and projects based on main topics. This type of clustering is one of the first developed unsupervised algorithms for classification of texts based on the similarity of their contents. The analysis included text from the titles and the abstracts from patent applications and research and innovation framework programmes. We elaborated further on the identification of possible topics that are common among the corpus of patents and projects in our sample by applying a topic modelling approach based on Latent Dirichlet Association.

IV. Data Analysis

In order to determine the emerging technology areas as described above, we retrieved 347 distinct patent applications. By looking into the IPC distribution of these patent applications, we extracted the top areas in which the applications were classified.

The analysis has shown that the *Instruments* represent the top IPC area, with exactly a quarter (25%) of all patent applications analysed. Above the 10% threshold are also *Transporting* (14%), *Engines or pumps* (14%), *Shaping* (11%), *Engineering in general* (11%) and *Electricity* (10%). The highest number of patent applications filed were attributed to the IPC sub-class G05D 1/00 - *Control of position, course, altitude, or attitude of land, water, air, or space vehicles, (e.g., automatic pilot)*. Apart from the class G05D 1/00, classes still trending high in patent applications are G08G 5/00 and G05D 1/10. Unsurprisingly, all IPC sub-classes in top 10 of the research are related to vehicle technologies and parts, navigation and traffic control. Regarding the NACE classification, as expected, the *Motor vehicles* area is represented in the majority of applications, with 16%. Among the frontrunners are also *Energy machinery* and *Other transport equipment* (both with 11%). Above the 5% limit are *Measuring instruments* (7%), *Rubber and plastic products* (7%), *Fabricated metal products* (5%) and *Office machinery and computers* (5%). When we take a deeper look into NACE classification, it appears that two NACE codes stand out. These are *Manufacture of general-purpose machinery* (NACE code 28.1) with 16% and *Manufacture of motor vehicles* (NACE code 29.1) with 11%. Other NACE codes which are highly represented in the total number of applications are *Manufacture of engines and turbines, except aircraft, vehicle and cycle engines* (NACE code 28.11) with 8%, *Manufacture of instruments and appliances for measuring, testing and navigation; watches and clocks* (NACE code 26.5) with 7% and *Manufacture of rubber and plastic products* (NACE code 22) with 5%. The expanded list is given in Table I.

TABLE I
Top 10 NACE Codes

Rank	Top 10 NACE codes in total number of patent applications	Share
1.	Manufacture of general-purpose machinery [28.1]	16%
2.	Manufacture of Motor Vehicles [29.1]	11%
3.	Manufacture of Engines and Turbines, Except Aircraft, Vehicle and Cycle Engines [28.11]	8%
4.	Manufacture of Instruments and Appliances for Measuring, Testing and Navigation; Watches and Clocks [26.5]	7%
5.	Manufacture of Rubber and Plastic Products [22]	5%
6.	Manufacture of Communication Equipment [26.3]	4%
7.	Manufacture of computers and peripheral equipment (26.2)	3%
8.	Manufacture of other electrical equipment (27.9)	3%
9.	Manufacture of Other Non-Metallic Mineral Products [23]	3%
10.	Manufacture of Other Transport Equipment [30]	3%

Regarding the period analysed, the applications in the area of *Motor vehicles* are on a constant rise. In contrast, the surge has been steep in the areas of *Energy machinery* and *Other transport equipment*, where the application volume doubled from 2012-2016. On the opposite, the Rubber and plastic products area reached its peak in 2012, but the number of patent applications in this area has been decreasing since. The average rising trend of the top 7 NACE areas is also not followed by the *Fabricated metal products* category.

In order to identify similarities that could point to emerging technology trends and spillovers between EU funded research projects and patent applications, we performed hierarchical clustering based on Ward's method [37] and identified three main clusters of documents. The titles and abstracts of both patent applications and project proposals comprised a text corpus which was pre-processed and analysed using the Quanteda package for the quantitative analysis of textual data in R statistical programming language. The pre-processing steps included harmonisation, removing punctuation, tokenisation, removing stop-words and stemming prior to clustering. A metric based on term frequency inverse document frequency (tf_idf) is used for the calculation of similarities between the documents. The first cluster contained 651 documents (27% were patent applications), the second with 185 documents was almost entirely composed by patent applications (79%) and the final one contained 607 documents which were almost exclusively projects (over 98%).

Hierarchical clustering is deterministic, and the resulting clusters are determined by the similarity metric associated with the method of choice. Topic modelling on the other hand is a method of unsupervised classification of documents in natural groups of topics which are not known beforehand. The most popular method is called Latent Dirichlet Association (LDA) which treats each document as a mixture of topics and each topic as a mixture of words. The resulting clusters allow for overlaps, meaning that certain documents may cover more than one topic and thus falling with some probability to more than one of the resulting clusters. In what follows, we present the results of topic modelling. For the analysis, we assumed three main topics and we were able to identify the top-10 terms by topic (Fig. 1) and the percentage of documents that are well described by topics 1, 2 and 3 respectively (Fig. 2). In Fig. 1 we see the documents in the corpus cluster in three main topics which deal with engine components and materials (topic 3), power generation and flight control (topic 2) and finally a topic related to positioning and connectivity units (topic 1). In Fig. 2 we see the documents allocated to the three topics with high probability and those among them covering more than one topic. Approximately 200 documents fall under topic 1 with probability 1, more than 250 fall with absolute certainty in topic 2, while almost 400 in topic 3.

We next discuss which of the three topics that we defined in the previous analysis comprise the three main clusters that were identified based on hierarchical clustering. To this end, we define a threshold of per-document-per-topic probability equal to 0.75, meaning that we classify a document into a specific topic if the per document-per-topic-probability is over 75%. By using this criterion, we found that, among the 651 documents in the first cluster, 164 fall into topic 1, 119 into topic 2 and finally

215 in topic 3. The second cluster mainly comprises documents from topic 2 with 128 of the 185 documents pertinent to this topic, 23 and 20 pertinent to topic 1 and topic 3 respectively. Finally, the third main cluster contains mainly documents that are pertinent to topic 1 (207 documents) and topic 3 (279 documents).

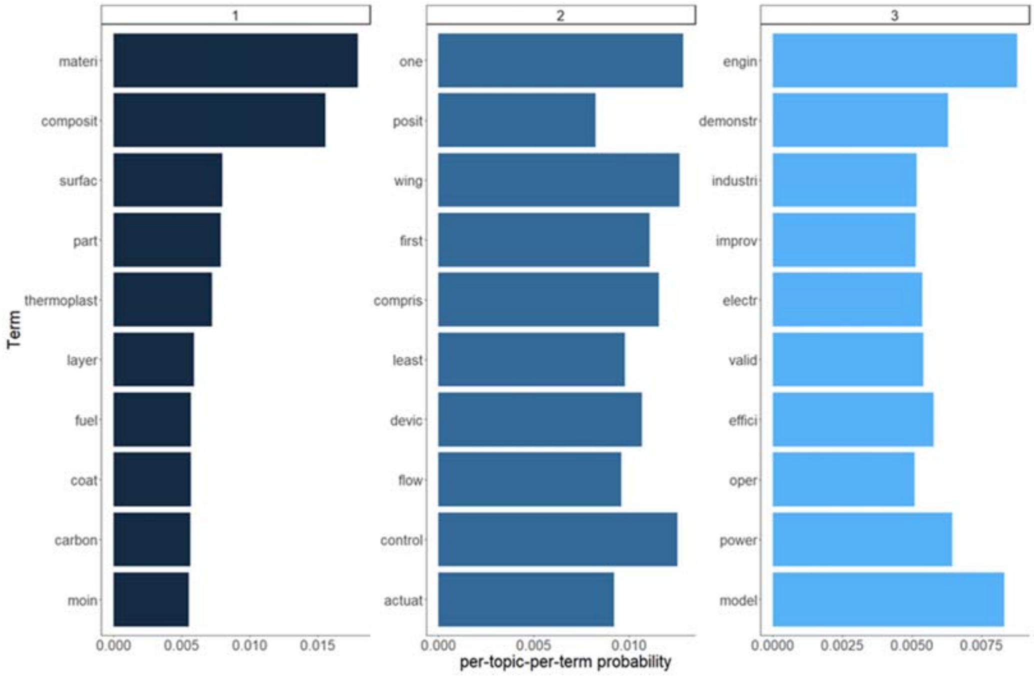

Fig. 1 Three main topics in aeronautics

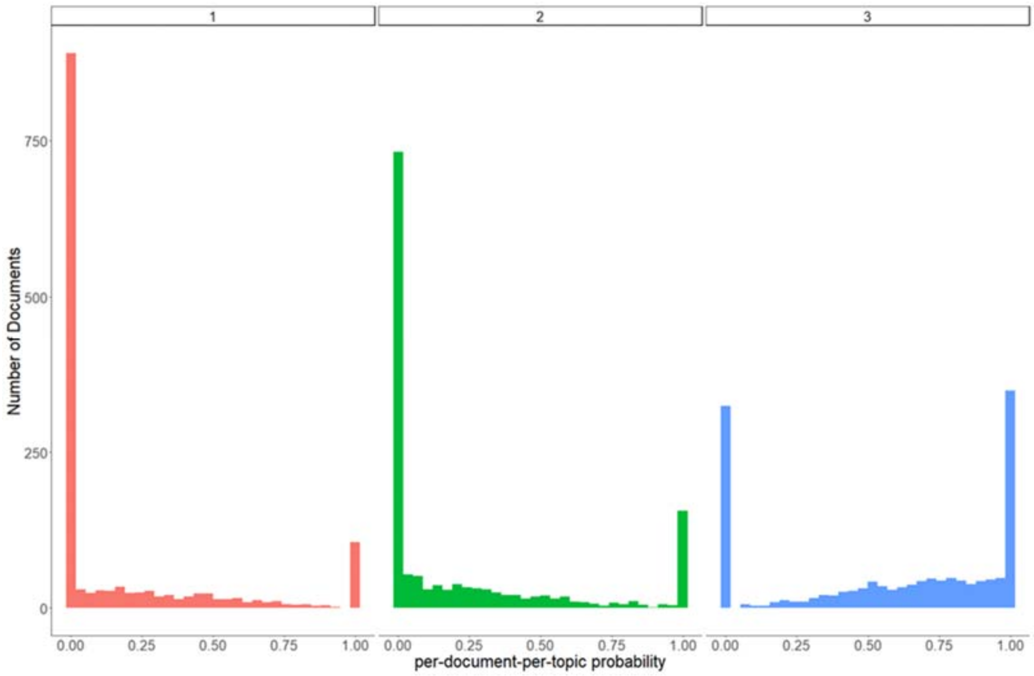

Fig. 2 Documents described by three sets of topics in aeronautics

In terms of the collaboration intensity in patent activity in the area of aeronautics, the results show that the regions from France, Germany, United Kingdom and Spain are among the top-10 regions. The collaboration intensity for entire Europe is demonstrated in Fig. 3.

The analysis has shown that only three regions are represented with above 5% in the total number of patent applications, including collaboration between innovators from different regions. These are Midi-Pyrénées with 11.3%, Hamburg with 5.6% and Oberbayern with 5.4%. The full table with collaboration networks for top ten NUTS2 regions in the analysis is given in Table II.

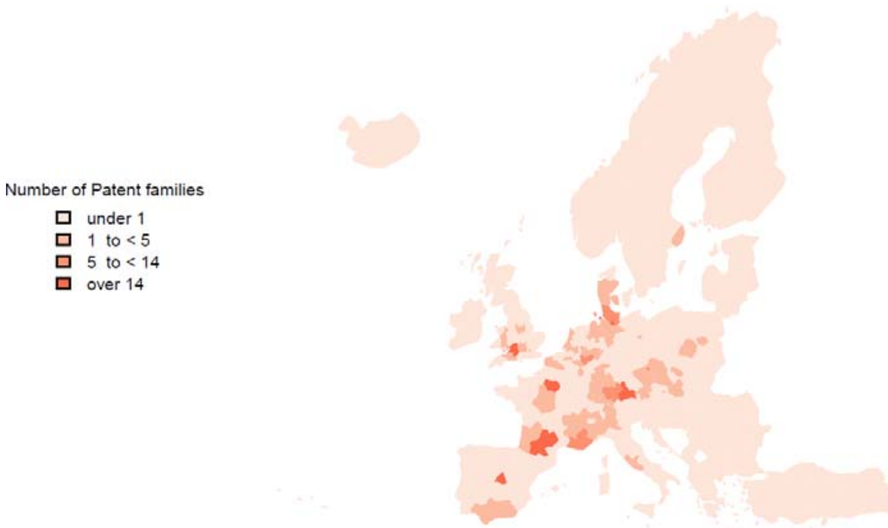

Fig. 3 Innovation collaboration intensity in aeronautics (by patent families)

TABLE II
EUROPEAN REGIONS WITH THE HIGHEST REPRESENTATION FOR INNOVATORS IN PATENT APPLICATIONS FOR AERONAUTICS WHICH INCLUDE COLLABORATIONS

Rank	NUTS2 region	Country	% of all patent applications
1.	Midi-Pyrénées (FR)	France	11.30
2.	Hamburg (DE)	Germany	5.60
3.	Oberbayern (DE)	Germany	5.39
4.	Île de France (FR)	France	4.87
5.	Gloucestershire, Wiltshire and Bristol/Bath area (UK)	United Kingdom	4.25
6.	Comunidad de Madrid (ES)	Spain	2.80
7.	Inner London (UK)	United Kingdom	2.59
8.	Provence-Alpes-Côte d'Azur (FR)	France	2.28
9.	Köln (DE)	Germany	1.87
10.	Schwaben (DE)	Germany	1.55

Table III includes data on the frequency of collaboration between the top-five filing regions in aeronautics in Europe with regions from other EU countries.

In total, aeronautics features among S3 priorities at 12 from the top 30 regions in cooperation, which represents 40% of the cases. More detailed collaboration patterns are given in Fig. 4.

As the Fig. 4 shows, the innovative landing technologies, procedures and devices are the most prominent area in cooperation between the Gloucestershire, Wiltshire and Bristol/ Bath region and the Midi-Pyrénées and Île de France regions. In the case of joint innovation projects between innovators from the same UK region and Hamburg, wing technologies feature as the top area. The sole Spanish region among the top regions, Comunidad de Madrid, has airplane body as the most frequent topic of collaboration with both Midi-Pyrénées and Hamburg. On the other hand, the analysis has also shown that engine technologies are in the focus of collaborations between innovators from Oberbayern and French regions of Provence-Alpes-Côte d'Azur and Île de France. Unlike these, in the case of the collaboration pattern between Oberbayern and Midi-Pyrénées regions, technologies related to aircraft controllability are dominant. When we look at the two regions with the highest number of collaborating patent applications, Midi-Pyrénées and Hamburg, the picture is quite different. The dominant area of collaboration there relates to technologies about cargo elements in the aircraft. Finally, the analysis of patent applications with innovators from the regions of Île de France and Köln points out glass technologies as the main collaboration area.

TABLE III
TOP INNOVATION REGIONS AND COLLABORATING REGIONS IN PATENT APPLICATIONS FOR AERONAUTICS WHICH INCLUDE COLLABORATIONS

Rank	NUTS2 region	Top collaborating regions	Share of all patent applications
1.	Midi-Pyrénées (FR)	Hamburg (DE)	19.11
		Comunidad de Madrid (ES)	13.38
		Gloucestershire, Wiltshire and Bristol/Bath area (UK)	12.10
2.	Hamburg (DE)	Midi-Pyrénées (FR)	46.15
		Gloucestershire, Wiltshire and Bristol/Bath area (UK)	15.38
		Comunidad de Madrid (ES)	6.15
3.	Oberbayern (DE)	Provence-Alpes-Côte d'Azur (FR)	16.67
		Île de France (FR)	12.50
		Midi-Pyrénées (FR)	6.94
4.	Île de France (FR)	Oberbayern (DE)	13.05
		Gloucestershire, Wiltshire and Bristol/Bath area (UK)	7.25
		Köln (DE)	7.25
5.	Gloucestershire, Wiltshire and Bristol/Bath area (UK)	Midi-Pyrénées (FR)	26.87
		Hamburg (DE)	14.92
		Île de France (FR)	7.46

Concerning the collaboration in the research and innovation framework programmes in aeronautics, the list of leading regions is slightly different from the one in the case of patent applications. The countries with the leading regions still include France, Spain, Germany and the United Kingdom, with the surge of Italian regions, but the leading regions themselves are somewhat different. In this sense, there is a significantly increased activity by Italian and Spanish regions where the highest collaboration projects rate was recorded in Campania and Pais Vasco. The entire collaboration landscape in the research and innovation framework programmes in the field of aeronautics is given in Fig. 5. In contrast, Table IV shows the top ten regions in that regard.

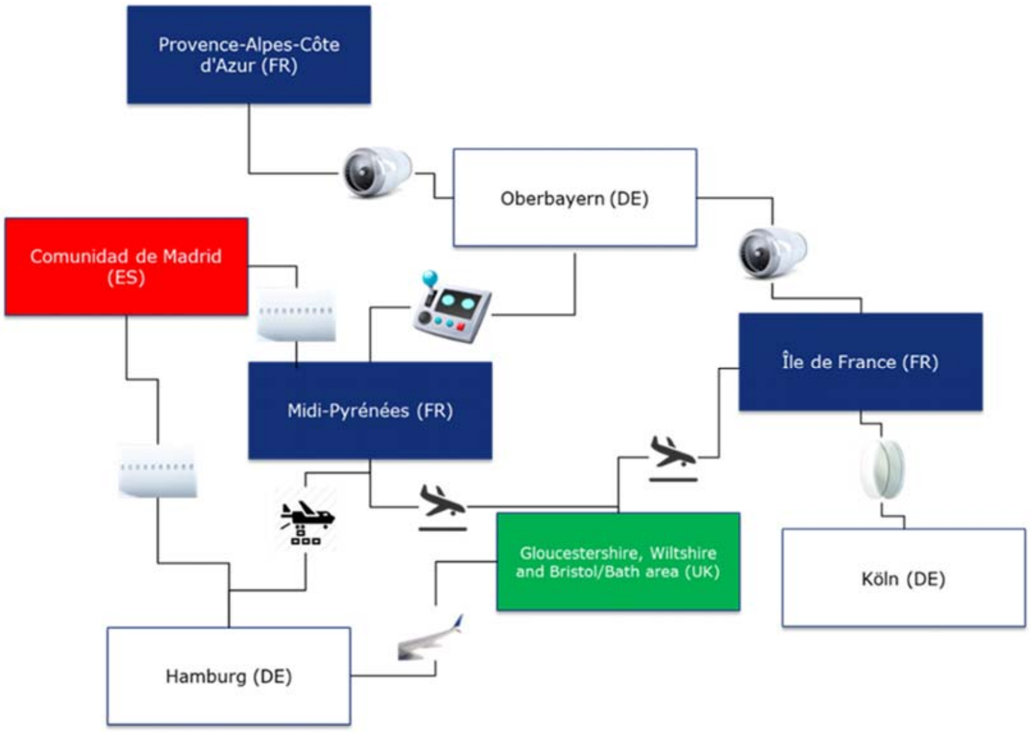

Fig. 4 Cooperation network with most frequent subject of innovation

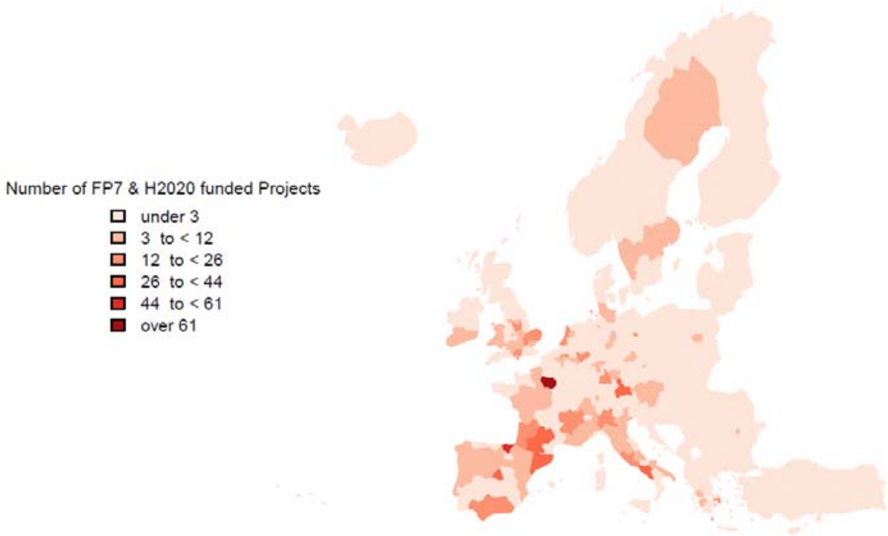

Fig. 5 Innovation collaboration intensity in aeronautics (by projects)

Table IV includes data on demonstrated international collaboration for the top-five regions within the research and innovation framework programmes in aeronautics. The regions are ranked by the fractional count of total projects.

V. Results and Discussion

The majority of the regions with aeronautics featuring within priority areas of Smart Specialisation is active in establishing innovation collaboration. However, among the top-25 regions in terms of collaboration in patent applications, only 8 have aeronautics as a Smart Specialisation priority on the first or second level. Out of 33 EU regions that had aeronautics (incl. aerospace) as their priority domains, 25 regions demonstrated collaboration activities in terms of patent applications. The share of EU regions with S3 priority domains featuring aeronautics is 11.6%. In comparison, the share of patent collaborations with at least one of the regions with aeronautics among S3 priority domains is 27.0% from all patent collaborations. In terms of research and innovation framework programmes, 27 EU regions recorded participation in either FP7 and/or H2020 programmes in the observed period. Also, a total of 47.52% of all participants in R&I programmes in aeronautics have aeronautics as priority area (with the threshold of having at least 10 participants per region, per framework programme).

TABLE IV
TOP COLLABORATING REGIONS IN R&I FRAMEWORK PROGRAMMES IN AERONAUTICS

Rank	NUTS2 region	Top collaborating regions	Share of all projects
1.	Île de France (FR)	Midi-Pyrénées (FR)	5.17%
		Attiki (GR)	2.93%
		Rhône-Alpes (FR)	2.37%
2.	Pais Vasco (ES)	Comunidad de Madrid (ES)	4.52%
		Castilla y León (ES)	2.09%
		Île de France (FR)	1.81%
3.	Campania (IT)	Lazio (IT)	3.86%
		Derbyshire and Nottinghamshire (UK)	2.46%
		Vlaams-Brabant (NL)	1.71%
4.	Comunidad de Madrid (ES)	Pais Vasco (ES)	5.69%
		Cataluña (ES)	4.13%
		Andalucía (ES)	2.51%
5.	Oberbayern (DE)	Stuttgart (DE)	2.71%
		Île de France (FR)	2.38%
		Köln (DE)	1.91%

Top collaborating regions in aeronautics in terms of patenting activity slightly differ from the same category when research and innovation projects are concerned. Top five regions from the first group include two French regions of Midi-Pyrénées and Île de France (FR), two German regions of Hamburg and Oberbayern, and one UK region of Gloucestershire, Wiltshire and Bristol/Bath area. The second group contains the French region of Île de France, two Spanish regions of Pais Vasco and Comunidad de Madrid, the Italian region of Campania and the German region of Oberbayern. Notably, Île de France is the only region that features highly in both tables, while Oberbayern and Comunidad de Madrid are among the top preferred region for collaboration in both cases. It should be also mentioned that the strong collaboration link between majority of top-ranked regions and Île de France was shown in both cases. The regions of Midi-Pyrénées and Gloucestershire, Wiltshire and Bristol/Bath area demonstrated greater activity in patent than in research project collaborations. This could be explained by the fact that these regions host Airbus facilities that can engage in intra-organisational innovation efforts which are more suitable for patent protection. On the opposite, the regions of Pais Vasco and Campania, the two regions among top five in research and innovation projects in aeronautics, have centres with significant research capacity in the aerospace/aeronautics domain. In such setting, innovation collaboration arrangements might not require extensive patenting activity.

When it comes to the most frequent collaborating regions in regard to patent activity, the picture is strongly shaped by Airbus intra-organisational innovation activity, as most of the regions host company's facilities. The strongest link was found between Hamburg and Midi-Pyrénées as well as between Gloucestershire, Wiltshire and Bristol/Bath area and Midi-Pyrénées. The analysis showed that major innovation centres have diverse specialised areas in terms of aircrafts. Engine and control related innovations are mainly produced in the Oberbayern region, the fuselage is the focal innovation in the Madrid region, Gloucestershire region appears to be the central point for innovations related to wings, brakes and landing systems. In contrast, the Midi-Pyrénées has a diverse portfolio or aircraft-related innovations.

In the goal of suggesting the emerging areas of technological advancement in aeronautics, we attempted to isolate differentiated groups of terms that appear more frequently together in patent applications and projects with the clustering methodology and topic modelling. The methodology applied here distinguished three separate groups or three clusters. The first one was solely based on patent applications, the second included both patent applications and projects data, and the third one was mainly based on projects. With the application of topic modelling, we identified three sets that suggest the constitution of separate clusters of technology areas. In that sense, the most populated group suggested an area of innovative engine components and materials, aircraft concepts and operational improvements. The second group comprised solutions focusing on power generation and control and management of aircraft and its parts. Lastly, the third group was established with the orientation towards positioning, connectivity units and composite material. This division is valid for the entire set of documents for both patent applications and projects. The findings suggest that the group concerning solutions on power generation and control and management of aircraft and its parts is more represented in the cluster where patent applications constitute majority. However, we did not find sufficient evidence on the probability of belonging to patent applications or projects for the other two groups.

VI. CONCLUSION

As aeronautics remains a strategic industry for Europe from the socio-economic perspective EU, especially in terms of jobs and income, it becomes increasingly important to realise its future directions, especially in the post-COVID environment. This industry was impacted first and hit the hardest by the circumstances surrounding COVID-motivated measures imposed by nations around the globe. Soon it became obvious that the unprecedented and brutal impact that the COVID crisis posed to the aeronautics required urgent action and careful elaboration of long-term survival steps for the sector. One of the means to tackle the stagnation or decline of an industry is to employ innovative solutions and build on the technology development to respond to the crisis.

This analysis intended to reveal the regions with the most intensive innovation collaboration in aeronautics, the effect of having aeronautics as a designated Smart Specialisation priority domain to innovation collaboration, and emerging technology fields that come from these collaborations. The results show that the portion of regions that engage in collaboration activities in regard to patenting is driven by the designation of aeronautics as a priority domain among the regions, especially if we consider top 10 collaborations in that regard. As expected, the regions oriented toward developing their competitiveness based on innovating in aeronautics demonstrate increasing patenting activity, although the extent is not very high. It is clear that Smart Specialisation, as strategic determinant for innovation policy development, plays a significant role in advancing innovation efforts in aeronautics in Europe. However, this role could be enhanced, especially having in mind research capacities of the regions that host aeronautics research facilities which do not necessarily operate under the Airbus umbrella. To that extent, the results of this study provide essential information in regard to the constituents of innovation potential of the aeronautics sector. Mapping of innovation potential in the regions that apply S3 approach, being a key element of the identification or update of priority areas strengths, should consider the findings that relate to the technology areas and collaboration patterns and include them in decision-making process when further policy measures are discussed.

The paper identified areas of high prowess in research and innovation collaboration activities in aeronautics in Europe. While there is a clear indication that the regions from France, UK, Germany and, to a certain extent, Spain dominate the innovation collaboration in the patent sphere, this landscape slightly changes with the collaboration concerning research framework programmes, where other regions, namely Italian and Spanish ones, fare more evidently. The observed difference in the most proactive regions in collaborations that relate to patent activity compared to collaborations in project activity in aeronautics can be explained by internal innovation activities performed by the Airbus company. The collaboration intensity in regard to patent activity is largely driven by the Airbus inter-organisational innovation efforts and procedures, as major company facilities are located in the Midi-Pyrénées, Hamburg, Madrid, Île de France and Gloucestershire, Wiltshire and Bristol/Bath area, which all appear among the top-10 patent application filing regions. Moreover, the results of collaboration in terms of patent activity among the top patenting regions seem to demonstrate a pattern in terms of the aircraft innovation areas or sections. In that regard, cooperation areas between the regions are driven by specific parts or systems in regard to the airplane, which is likely to be affected by the Airbus intra-organisational expertise in these regions.

As expected, Airbus intra-organisational links concerning innovation in aeronautics are not so apparent in the projects from research and innovation framework programmes, which are likely to include regions with innovation facilities that do not necessarily operate within the Airbus conglomerate. This coincides with almost a double share of participation of regions with aeronautics as S3 domain in the research and innovation framework programmes in comparison to the share of similar regions in total patent applications, again suggesting that the orientation towards advancing the aeronautics sector with Smart Specialisation is driven by the overall research capacity of diverse stakeholders that operate in these regions. The results may also suggest that while the analysis of research and innovation framework programmes in aeronautics revealed more ‘non-Airbus’ innovation landscape, the development of complementary innovation sources in these regions might have been amplified by Airbus itself. However, several regions from Spain and Italy that are proactive in research and innovation projects actively cooperate with the regions that are proactive in patenting activity, which may suggest spillovers that include Airbus-linked innovation efforts. This proposition is further supported by the study results, which support the view that one of the key regions in patenting activity and an Airbus site, Île de France, also represents a focal point of collaborative research and innovation efforts in aeronautics.

From the analysis of the main emerging technology areas in aeronautics, we observed three distinctive areas. In line with the findings, it can be concluded that the greatest share of innovation efforts is being invested into engine improvements and overall aircraft concept enhancements. These areas are also in the focus of the major Airbus innovation centres, which was particularly demonstrated in the collaboration action involving the Oberbayern region with the regions of Île de France and Midi-Pyrénées. However, significant portion of projects linked with these areas suggest that the areas are in focus of independent entities constituting major general research capacities on the continent. The field of engine improvements and overall aircraft concept enhancements is followed by the area of power generation and aircraft management control, which is, on the other hand, to a great extent covered by patent applications. This suggests that this area is more in focus of intra-Airbus and other business-oriented collaboration efforts. The third field that demonstrated a significant scope of directed innovation ventures includes positioning and composites. The analysis did not reveal any other area that would have sufficient distinctiveness and scope to be considered as another critical independent technological field.

VII. Limitations and Further Research

Although the findings aim at identifying the most prolific regions in collaboration in innovation in the domain of aeronautics, it needs to be emphasised that a substantial portion of the collaboration patterns relates to intra-organisational arrangements of the Airbus conglomerate. This circumstance has to be considered when analysing the results of this study. Further research could be directed into analysing the effects of the implementation of the Airbus innovation strategies on the development of innovation potential in aeronautics of the regions. Additionally, the effects of the commercialisation of the joint innovation efforts encompassed by this study should be further evaluated so that the efficiency of the collaboration is assessed.

As this study has been conducted in the midst of the crisis of the aeronautics sector due to the COVID-19 pandemic, future efforts should be invested into identifying the sector's recovery and development directions in the post-COVID era. This could imply analysing emerging fields in flight security and the collaboration arrangements in advancing the sector's recovery through innovation.

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