

Pishdadian, Hassan; Aubertin, Alain; Turkina, Ekaterina; Cohendet, Patrick; Simon, Laurent

Article

How aerospace clusters respond to the challenge of sustainability: A comparison of the Toulouse and Montreal clusters

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Hassan Pishdadian, Alain Aubertin, Ekaterina Turkina, Patrick Cohendet* and Laurent Simon

How aerospace clusters respond to the challenge of sustainability: a comparison of the Toulouse and Montreal clusters

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Abstract: This paper examines how aerospace clusters help shape the innovation dynamics of aerospace manufacturers in the environmental transition to develop sustainable commercial aircraft. It intersects the economic geography, innovation, and sustainability literatures to develop a theoretical framework about the conditions that facilitate such a transition, and uses the case of two major aerospace clusters, Montreal and Toulouse, as a testing ground. Using a mixed-methods approach combining social network analysis and a series of interviews with some of the key actors in each cluster, the main findings of the study highlight a major difference between the two clusters: while in Toulouse the transition towards sustainability is a top-down approach orchestrated by the crucial role of public authorities, in Montreal the transition is a bottom-up one initiated by an active group of actors from aerospace firms and university research centers. The study also suggests some paradoxical outcomes of collaboration and competition between the two aerospace clusters during this process of environmental transition. Our study aims to contribute new insights to the literature on sustainability transitions in clusters and to develop implications for cluster research and policy-making.

Keywords: sustainability; aerospace clusters; social network analysis; collaboration and competition between clusters

1 Introduction

According to Kivimaa et al. (2019), for all sectors of the economy “disruptive sustainability” implies a fundamental shift in established ways of doing things to meet the need for a broader transition to sustainable innovation models that include markets, business practices, business models, regulations and cultural models (Gambardella and McGahan 2010). The need to act on climate change is particularly urgent for the aerospace firms as commercial aircrafts are considered as one of the most highly visible polluting industrial products, with an estimated 2.4 percent of total CO₂ emissions in 2018.¹ A January 2021 study in the journal “Atmospheric Environment concluded that the climate impact of aviation accounted for 3.5 percent of total anthropogenic warming in 2011 and was likely the same percentage in 2018” (Overton 2022).² By 2050, “commercial aircraft emissions could triple given the projected growth of passenger air travel and freight” (Overton 2022).³ In addition, aerospace firms are facing a new generation of citizens and activists who are questioning the environmental and social impacts of air travel (Flaherty and Holmes 2020).

To address all these complex issues, many public and industry initiatives have been launched in recent years to support research and innovation in sustainable aerospace. For aerospace firms, the priority given to sustainability implies drastic structural changes in terms of aircraft design, propulsion systems and Sustainable Alternative

*Corresponding author: Patrick Cohendet, Department of International Business, HEC Montreal Departement d’Affaires Internationales, Montréal, Quebec, Canada, E-mail: patrick.cohendet@hec.ca

Hassan Pishdadian, Department of Management, Strategy and Entrepreneurship, HEC Montréal, Montreal, Quebec, Canada

Alain Aubertin, Department of International Business, HEC Montreal Departement d’Affaires Internationales, Montréal, Quebec, Canada

Ekaterina Turkina and Laurent Simon, Department of Entrepreneurship and Innovation, HEC Montréal, Montreal, Quebec, Canada

1 Graver, Brandon, Kevin Zhang, Dan Rutherford. 2019. CO₂ Emissions from commercial aviation, 2018. International Council on Clean Transportation. (ICCT). Working Paper 2019–16. https://theicct.org/sites/default/files/publications/ICCT_CO2-commercial-aviation-2018_20190918.pdf.

2 Lee, David, D.W. Fahey, A. Skowron, et al. 2021. The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. *Atmospheric Environment*, 244. <https://reader.elsevier.com/reader/sd/pii/S1352231020305689>.

3 Karcher, B. 2016. The importance of contrail ice formation for mitigating the climate impact of aviation. *Journal of Geophysical Research: Atmospheres*. 121.7. 3497–3505. <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2015JD02469>.

Jet Fuels (SAJF) to reduce carbon footprint and improve fuel efficiency, infrastructure improvements, optimization of ground operations and airport functionality to reduce emissions, fleet optimization to minimize carbon emissions, etc.

These environmental, social and economic challenges call for new and enhanced forms of collaboration among aerospace industry stakeholders to shape a greener future for aviation, particularly in the world's major geographic aircraft manufacturing areas, such as the aerospace clusters of Seattle, Toulouse, or Montreal. These are major aerospace clusters that embody the concept of industrial clusters to concentrate resources, expertise and infrastructure in specific geographic areas. These clusters serve as focal points for local and global collaboration among industry players, research institutions, and government agencies.

Few studies have analyzed how these major aerospace clusters are managing the environmental transition and achieving sustainability. In particular, there is a lack of in-depth analysis of how recent environmental and social concerns affect the collaboration and innovation strategies of aerospace firms in these clusters, and how these structural changes might contribute to reshaping the economic geography and location strategies of the major aircraft manufacturers and their original equipment manufacturers (OEMs).

In this context, this study addresses the following research question: How have the specific characteristics of aerospace clusters (the nature of inter-firm relationships, the forms of collaboration with academic research, the role of public authorities, etc.) contributed to shaping the innovation dynamics of aircraft manufacturers in their efforts to meet the demands of sustainable development?

In the present study, in order to add to the literature addressing these issues, we analyze the case of the aerospace clusters of Montreal (Canada) and Toulouse (France), focusing on their similarities and differences in the way they cope with the need to develop a more sustainable aerospace industry. We will pay particular attention to the dynamics of knowledge exchange and mutual investment, as well as the dynamics of cooperation and competition between the two clusters in terms of international relations. In this comparative study of the Toulouse and Montreal clusters, we use two main methodological approaches: a network analysis and a series of semi-structured interviews with key representative actors in both regions.

The results of the study highlight the differences in the innovation dynamics pursued by the respective “champions” of the two clusters (Airbus for Toulouse and Bombardier for Montreal) in their efforts to meet sustainability requirements. One of the main findings of the study is that, over the past two decades, the innovation dynamics of the Toulouse cluster in the development of sustainable aircraft has been characterized by successive incremental innovations, while the Montreal cluster has clearly marked a major disruptive innovation towards sustainability.

The structure of the paper is as follows: in the next section, Part 2, we analyze the nature of the environmental transition challenges facing the aerospace industry. In Part 3, we characterize the structure of the two aerospace clusters of Toulouse and Montreal to better understand their respective assets and capabilities in trying to respond to the drastic environmental challenges. Part 4 describes the mixed-methods approach, consisting of a combination of social network analysis and interviews, to provide a nuanced analysis and comparison of the dynamics of the two respective ecosystems. Part 5 presents the main findings of the empirical studies. In Part 6, the discussion highlights the main similarities and differences in the respective paths taken by the clusters to respond to sustainability challenges and examines the complementarities of the two places in terms of new forms of cooperation triggered by the environmental transition. Part 7 concludes.

2 The sustainability challenge in aerospace industry

The growing need expressed by society to address sustainable challenges could be interpreted to a large extent as a drastic change that seriously challenges the traditional modes of production of commercial aircraft and the location strategies of aerospace firms, and how these structural changes could contribute to reshaping the economic geography and location strategies of the major aircraft manufacturers and their OEMs in particular.

In all aerospace clusters, economic, political and social decisions have traditionally supported the competitiveness of their respective local “champions” (Airbus in Toulouse, Bombardier in Montreal, Boeing in Seattle, etc.). This support has taken many forms: helping to finance the resources needed to develop aircraft, air links, and other aerospace uses, whether in the form of airport infrastructure and industrial facilities; providing the resources and energy

needed for production and flight; funding cutting-edge R&D, training, and support for the specialized workforce; or facilitating economic arrangements that make air transport more competitive or attractive than its terrestrial alternatives.

In terms of sustainability, the last decade has seen increased support for improving the sustainability of aircraft, for example by targeting engine fuel consumption or airframe weight. However, these forms of innovation can be seen as incremental, addressing improvements in some components of the aircraft. At a time when nearly all sectors of the economy are simultaneously trying to achieve their own sustainability and growth goals in an increasingly uninhabitable, pressurized environment and with fewer resources, the prioritization of resources and financial support for aerospace firms requires more disruptive forms of innovation to fundamentally rethink the way a commercial aircraft is produced.

Responding to these challenges is even more urgent as time is running out and social acceptance of the sector is being questioned. While the sector's sustainability targets are often set for 2050, the greatest uncertainties are around 2040 (Bouckaert et al. 2021). Indeed, the development and certification lead times for technologies that promise sustainability breakthroughs (new platforms, new fuels) mean that their large-scale deployment would not be plausible before 2040. However, other factors could evolve very rapidly between 2024 and 2040, such as the rapid degradation of a livable environment and rapid advances in sustainability in other sectors, with growing concerns about social acceptability (Hansmann and Binder 2021). It is therefore plausible that the interaction between these time scales will be particularly pronounced around 2040 and will play a major role in shaping the future.

Sustainability goals for the sector are most often expressed in terms of roadmaps, a form of anticipation that assumes both that the future in which the sector will develop is predictable and that the sector has a strong agency over its own future. While this approach has been relevant for the past few decades, it is about to change completely. Even with colossal investments in technological development, the sector will have limited agency over its own future because of the unpredictability of its context and because it is plausible that the sector will lose influence over the trade-offs that could affect its future. The new context is such that multiple sectors are now competing for their limited share of total global emissions, for access to offsets, for access to low-carbon energy sources, for access to sustainable and equitable biomass, or for access to increasingly

scarce materials (Åkerman 2005; Dias et al. 2022; Gangi et al. 2022).

The telos of the sector is therefore: Which aerospace, for whom and why, in a society in transition, to mitigate the degradation of a livable environment and to adapt to the degradation already underway? What is the role of specialized territories in this telos? From a practical perspective, the main challenges facing aerospace manufacturers in addressing sustainability issues are therefore very significant. These include: (i) labor availability due to deteriorating health, barriers to mobility, competitive talent markets, etc.; (ii) availability of parts, materials, industrial capacity, and energy depends on globalized supply chains that become unpredictable due to climate hazards, labor availability, and geopolitical uncertainties (Hallstedt et al. 2015); (iii) optimization of aircraft performance: Global warming reduces performance (ICAO 2013, 2022a,b).

For example, a global warming of 5 °C would correspond to an estimated 10–20 % reduction in aircraft payload capacity – this payload reduction occurs because higher temperatures reduce air density, which in turn reduces the lift generated by aircraft wings. As a result, aircraft require longer runways to take off and are forced to carry lighter payloads to operate safely in such conditions. This phenomenon highlights the vulnerability of aviation to climate change and the need for adaptation strategies to mitigate its operational and economic impacts (Bravo et al. 2022). Among these strategies, transitioning to alternative energy sources has gained significant attention. For instance, a switch to electricity, including technologies such as batteries, SAF electric fuels, and hydrogen, could reduce aviation's carbon footprint. However, the production and distribution of low-carbon electricity face challenges from climate hazards, such as water shortages for cooling nuclear power plants or damage to distribution networks (Undavalli et al. 2023; Viswanathan et al. 2022). Similarly, switching to biofuels presents its own risks, as biomass production is increasingly impacted by unpredictable agricultural yields, climate hazards, and wildfires (Yilmaz and Atmanli 2017).

These urgent needs to act on climate change and to move towards a new economic regime that prioritizes sustainable development goals imply a drastic change in the structures of aerospace clusters. Faced with such a wide range of complex and systemic issues, the aerospace industry is challenged to regroup and innovate (also by opening up to other sectors such as digital innovation, green tech or artificial intelligence...). In the following section, we examine the two aerospace clusters of Toulouse and Montreal to better understand their respective assets

and capabilities to respond to these drastic environmental challenges.

3 Innovation within and between on aerospace clusters

3.1 Aerospace clusters

According to Malmberg and Maskell (2002: p. 430) clusters are “spatial agglomerations of similar and related economic activities that are characterized by localized capabilities and untraded interdependencies”. The dynamic nature of clusters is based on local competition between firms, supply of equipment and services, input factors (human capital, research infrastructure, venture capital) and demand factors (sophisticated local users). Aerospace clusters belong to this category of industrial clusters (Broekel and Boschma 2012; Niosi and Zhegu 2005, 2010; Turkina et al. 2016), but they have the following main specific characteristics that distinguish them from other more traditional industrial clusters, such as automotive or textile:

- Aerospace clusters are high-tech clusters where innovation is usually the result of collaboration between firms (mainly their R&D departments and technology and service suppliers), research organizations (universities, research institutes, laboratories, etc.) and public authorities. Within these clusters, government support for business R&D is strategic.
- These clusters are concentrated in a limited number of geographical areas around the world. The major civil aircraft assembly clusters (Seattle, Toulouse, Montreal, etc.) with leading firms such as Boeing, Airbus, and Bombardier are located in developed countries and act as attractors for other firms such as specialized suppliers, subcontractors, and service firms to locate together, creating hub-and-spoke industrial clusters that benefit from the regional pool of skilled and semi-skilled labor (Gray et al. 1996). Aerospace regions that produce the major components of an aircraft (fuselage, wings, engines, avionics, landing gear, etc.) are specialized. For example, the major engine clusters are located around GE’s engine plants in Cincinnati, Ohio, and Lynn, Massachusetts; the wing structure of the Boeing 787 Dreamliner is produced in an industrial cluster in Japan, while Seattle specializes in engineering for large commercial aircraft.
- Aerospace clusters are characterized by a high degree of geographic inertia, due to high sunk costs in large plants that are used for decades, with expensive and complex sophisticated equipment that cannot be easily moved from one location to another.
- Economic concentration within these clusters is very high. For each major type of aerospace product (large civil aircraft, regional aircraft, business jets, helicopters, etc.), there are only a few competitors, with very high barriers to entry due to the capital commitment required to design and produce aircraft. The aerospace industry is generally organized hierarchically into “tiers.” Leading firms tend to specialize in a systems integration role focused on the airframe of an aircraft, while outsourcing the production of major subsystems (engines, avionics, controls, landing gear, etc.) to technically sophisticated subcontractors known as Tier 1 integrators. These suppliers, in turn, rely on Tier 2 suppliers for the production of smaller subsystems such as computer systems, wing flaps, transmissions, and so on. Lead and Tier 1 firms act as attractors for other firms such as specialized suppliers, subcontractors, and service firms to locate, creating hub-and-spoke industrial clusters (Gray et al. 1996).
- Within aerospace clusters, informal knowledge sharing among aviation professionals and experts is facilitated by the mobility of industry personnel (Malmberg and Power 2005; Millar and Salt 2008) and the presence of multiple collaborative spaces. Tacit knowledge is deeply embedded in the organizational culture of aviation firms (Evers et al. 2010), highlighting the importance of physical proximity and face-to-face interaction in these clusters.
- As Paone (2016: p. 20) points out, in the aerospace industry, “the (international) supply chain is the only channel for knowledge spillovers,” which arise through mechanisms such as inter-firm partnerships or original equipment manufacturer (OEM) training schemes that allow knowledge to be transferred between organizations and across regional boundaries. On the other hand, the globalization of supply chains has led to a high degree of regional specialization in the production of high-value-added products, creating a self-reinforcing mechanism in which specialization strengthens the international dimension of knowledge spillovers. Supply chain management involves several dimensions, including product co-development, supplier certification, and cost sharing (Bozdogan et al. 1998; Gostic 1998). Aerospace prime contractors have moved from American-style arm’s-length procurement to collaborative, “Japanese-inspired” practices that share knowledge about products, processes, and costs.

- Subsystem producers with plants and offices in major aerospace clusters facilitate global knowledge exchange through cross-border pipelines (Bathelt and Li 2020; Lorenzen and Mudambi 2013). These pipelines circulate codified knowledge in areas such as aircraft technology, sustainable fuels, and air traffic management. Regular international trade shows further reinforce knowledge sharing, networking, and competitive positioning (Maskell et al. 2004). As a result, the aviation industry is aligned with Bathelt and Li's (2020) four-stage model for building cross-border pipelines, which includes site selection, knowledge facilitation, local embedding, and global knowledge generation.

After this review of the main characteristics of aerospace clusters, we will now present the cases of the Toulouse and Montreal aerospace clusters in order to better understand and compare their evolutionary history, specific structures and modes of interaction. Such an analysis will allow us to better examine, in the empirical study that follows, how these well-structured clusters have managed their paths towards a new regime of innovation for sustainability.

3.2 The Toulouse aerospace cluster

The Toulouse aerospace cluster concentrates most of the design and manufacture of large commercial aircraft, in particular the breakthrough investments of Airbus (H2, batteries, flight configurations, AI, VTOL, drones, etc.). Since 2019, Airbus is the world's largest manufacturer of

commercial aircraft. For those who have visited Toulouse, it is clear that Airbus' influence on civil aeronautics research is considerable. This is particularly evident at its headquarters, where the firm's weight is felt in many ways. In addition, the French government, the Occitanie region and Greater Toulouse itself play a major role in supporting research, innovation and industrial development. This collective effort has resulted in Toulouse becoming a hub for aeronautical research and development.

The public authorities have always played a leading role in supporting, regulating and promoting the Toulouse aerospace cluster. The Regional Council promotes innovation by financing cooperation institutions (IFC) and helping SMEs to access talent and implement appropriate financing instruments. The French Ministry of Industry enforces the industrial policy framework, while the Ministry of National Education invests in the development of technical skills, in particular through relations with several prominent "Grandes Écoles", including ENAC (French National Aeronautics School) or ISAE-SUPAERO (Higher Institute of Aeronautics and Space). Finally, the European Union oversees competition in the aviation industry and establishes regulations regarding aircraft safety, noise, and environmental impact (Porter and Takeuchi 2010, see Figure 1).

Hickie (2006) highlights the critical role of knowledge and skills in enhancing the competitiveness of aerospace hubs such as Toulouse. Successful firms are characterized by early design achievements, government support, and strong customer relationships, while continuous operations and ongoing knowledge development are key to maintaining competitiveness.

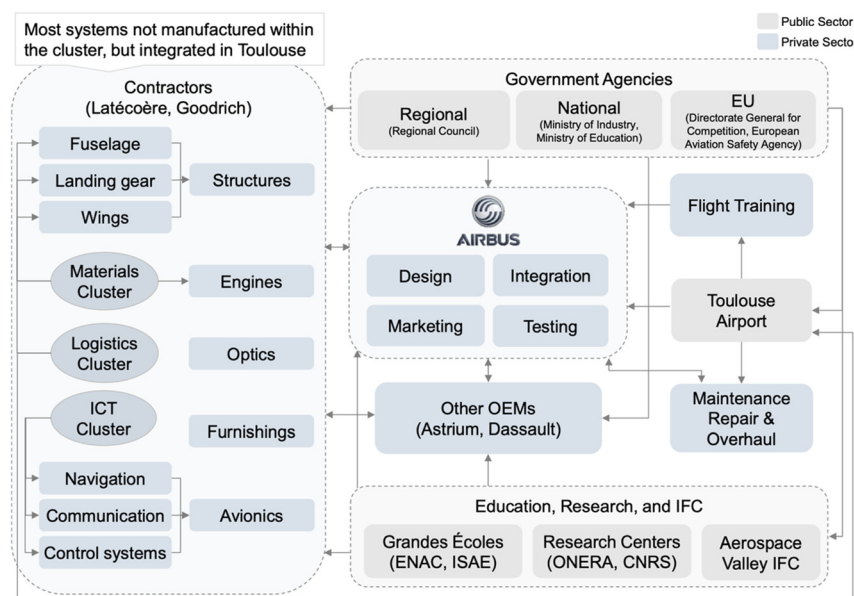


Figure 1: Key actors and interconnections in the Toulouse aerospace cluster (source Porter and Takeuchi 2010: p. 17).

Over time, despite global challenges, Toulouse and similar regions have remained resilient by leveraging their expertise in technology, management, and organizational strategies. This has been achieved through key collaborative consortiums such as Aerospace Valley⁴ created in 2005, which bring together major aerospace manufacturers, OEMs, start-ups and university centers.

Over the past decade, the intense competition between Boeing and Airbus to become the world's largest manufacturer of commercial aircraft has led both sides to focus on reducing the cost of producing an aircraft to the lowest price on a regular basis, which, as we will see in the empirical study, has to a large extent prevented the two giants from focusing on sustainability issues earlier.

3.3 The Montreal aerospace cluster

Unlike Toulouse, where the weight of government support is predominant, the development of Montreal's aerospace cluster is the result of a series of initiatives by private firms, mostly focused on the production of small and regional aircraft (Emilien et al. 2019; Galvin 2019; Kitajima 2020). The most important firm is Bombardier, which bought Canadair in 1986 and decided to enter the regional aircraft market. The aerospace sector in Montreal is characterized by a tight network orchestrated by key contractors and intermediaries that promotes collaboration and partnership (Gardes et al. 2015). This network has developed over time through close interactions among stakeholders, including regular meetings and physical proximity (Hassen et al. 2012). The Montreal aerospace cluster includes key firms such as Bombardier, Bell Textron Canada, CAE, Héroux-Devtek, CMC, and Pratt & Whitney Canada, which exert significant influence and provide a centralized governance framework for their partners and subcontractors. Table 1 provides a comprehensive overview of the key stakeholders in the Montreal aerospace cluster, including these firms, along with universities and intermediary organizations. It highlights their roles in fostering collaboration and driving innovation across the ecosystem. As Niosi and Zhegu (2005: p. 17) points out, "international knowledge spillovers are thus the norm for all the large manufacturers operating in the region. Montreal generates and receives from abroad major knowledge externalities through its tier 1 and 2 producers".

Local aerospace firms are increasingly encouraging Montreal's universities to conduct academic research and increase the flow of graduates to meet their needs.

Table 1: Key stakeholders and supporting entities in the Montreal aerospace cluster adapted from Niosi and Zheng (2005: p. 14).

Firms	Universities	Intermediaries
Bombardier	Polytechnique Montreal	CRIAQ
Pratt & Whitney	Concordia University	Aéro Montréal
CAE	McGill	GARDN
Héroux-Devtek	ETS	SA ² GE
Messier Dowty (Safran)		AQA
Thalès		Québec government
Honeywell		Federal government

Polytechnique Montreal, the dominant local engineering school, which received its first aeronautics chair from Bombardier in 1986, now has 16 aeronautics chairs and more than 38 research units with aeronautics and transportation infrastructure.⁵ In 2001, Concordia University became home to the newly created Concordia Institute for Aerospace Design and Innovation (CIADI). CIADI was an initiative of seven major Montreal aerospace firms.⁶ The AÉROÉTS group at the École de Technologie Supérieure, another major local engineering school, has partnered with other academic institutions and research centers to create Aerospace 4.0, an integrated program of aerospace research and education.⁷ Finally, the McGill Institute for Aerospace Engineering (MIAE) helps student network and secure local internships, giving them first-hand experience and a head start in the industry.⁸ As of 2020, Bombardier itself is supporting a very ambitious internship program that aims to attract more than 1,000 candidates per year.⁹

Montreal's aeronautics cluster is also strongly supported by intermediary organizations such as GARDN (Green Aviation Research & Development Network), Aero-Montreal and CRIAQ (Consortium for Research and Innovation in Aerospace in Québec).

In Montreal, the most significant aviation industry achievement of the past decade has been the development and certification of the Bombardier C Series aircraft. This innovative design is highly efficient in terms of both environmental impact and fuel consumption, making it the most

⁵ https://www.polymtl.ca/aero/?utm_source&tnqx3d;chatgpt.com.

⁶ https://www.concordia.ca/ginacody/ciadi/about.html?utm_source=chatgpt.com.

⁷ https://www.etsmtl.ca/en/news/aerospace-4-0-fourth-industrial-revolution-applied-aerospace?utm_source&tnqx3d;chatgpt.com.

⁸ https://www.mcgill.ca/miae/home?utm_source&tnqx3d;chatgpt.com.

⁹ <https://bombardier.com/en/careers/internship/internship-canada>.

⁴ <https://www.aerospace-valley.com/en/node/1>.

efficient aircraft in its class (Stephenson 2024). The Bombardier C Series program was launched on July 13, 2008. The first aircraft (CS100) made its first flight in September 2013 and entered service with Swiss Global Airlines in July 2016. The longer version (CS300) first flew in February 2015 and entered service with airBaltic in December 2016. As we will discuss under, the C-series program was bought by Airbus in October 2017.

4 Methodology and analysis

We use a mixed methods approach that consists of a combination of social network analysis (SNA) that is used to portray differences in the structural organization of both clusters and a series of interviews to provide a nuanced analysis and comparison of the two ecosystems. Aerospace clusters are inherently complex, involving interactions between different actors, including firms, research institutions and governments. SNA allows us to quantify and illustrate the structure of these interactions, revealing differences in network density, centrality and governance mechanisms. By capturing these metrics, SNA provides a robust means to systematically compare the structural organization of the Toulouse and Montreal clusters. Our data collection for the network analysis part consisted of two steps. In the first step, we used cluster directories to identify the nodes of the network (firms, universities and research institutions, and government agencies) in the two clusters. For Montreal, we identified 297 actors. In Toulouse, we identified 394 relevant actors. In a second step, we mapped the inter-organizational network for each cluster by collecting information on the collaborative ties between cluster actors. As is common in social network analysis, we measured linkages on a binary scale, using 1 if there is evidence of a formal relationship and 0 otherwise (Fortunato 2010). The data reflect collaborative networks that existed in clusters in 2023. The information used to identify linkages came from cluster reports, press releases, firm reports, information on collaborative projects published by government agencies and research institutions, as well as Spiderbook, CSI market, Thomson Reuters Eikon, and Bloomberg databases (see the Appendix for a list of the main data sources). While we cannot claim to have captured every inter-organizational link, we were able to cover all of the major projects and partnerships occurring in both ecosystems.

While SNA provides a macro-level view of inter-organizational linkages, it does not fully capture the motivations, perceptions and contextual factors that influence these relationships. Semi-structured interviews complement the SNA by providing qualitative insights into the roles

of key actors and the dynamics of collaboration influences shaping sustainability transitions. This layered approach ensures both breadth and depth in our analysis.

For the qualitative part of our analysis, we conducted 26 semi-structured interviews during the spring of 2024 with key stakeholders across both ecosystems, including industry experts, top executives, and representatives from leading research institutions such as Innovitech, Aerospace Valley, Bombardier Aviation, ENAC, ISAE SUPAERO, and Airbus Canada. The selection criteria focused on individuals deeply involved in collaborative aerospace projects, particularly those addressing sustainability transitions within the Montreal and Toulouse clusters. These individuals were chosen for their leadership roles in managing innovation portfolios, fostering strategic relationships within their ecosystems, and their substantial contributions to decarbonization efforts – many spanning over two decades.

A total of 49 individuals were invited to participate, with 26 agreeing, yielding a response rate of 53 %. The virtual format via Zoom provided a practical solution for accommodating participants across diverse geographical locations and time zones. Each one-hour interview explored the evolving dynamics of aerospace ecosystems in response to sustainability imperatives, emphasizing both regional and global challenges. The interviews were audio-recorded (with consent), transcribed verbatim, and thematically coded to uncover patterns and insights relevant to the research question.

The focus of the interviews was twofold: (1) to understand the role of ecosystem actors – firms, academic institutions, and public organizations – in driving sustainability-focused innovation, and (2) to assess how these actors' collaborative efforts have shaped the structural and operational transitions within the clusters. The findings provided nuanced perspectives on the distinct top-down and bottom-up approaches employed by the Toulouse and Montreal clusters, offering critical context for interpreting the network analysis results.

The following sections present the network analysis of both clusters and the analysis of the interviews.

4.1 Network analysis of Montreal and Toulouse ecosystems

Both regions, Occitanie in France and Quebec in Canada, along with Montreal and Toulouse, are recognized as major aerospace clusters, embodying the concept of industrial clusters to concentrate resources, expertise, and infrastructure in specific geographical areas. These clusters serve as focal-points for collaboration between industry players, research institutions and government agencies. At the same

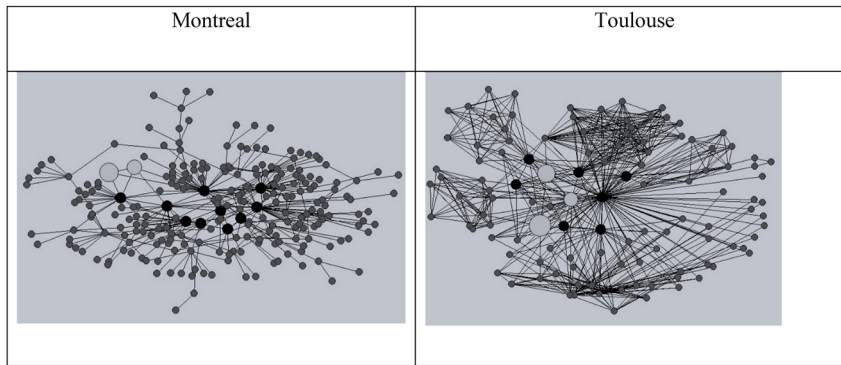


Figure 2: Montreal and Toulouse collaboration ecosystems.

time, there is an important difference related to organizational structure of the clusters, since Toulouse focuses on the design and manufacture of large commercial aircraft, while Montreal specializes mainly in the production of smaller regional jets.

Figure 2 shows the visualization diagrams of both ecosystems. We focus on the connected core of the network, excluding some peripheral clusters and nodes that have no connection to the main body of the network. Most of the central organizations that orchestrate the network are shown in black, government nodes are shown in yellow, and the rest of the nodes are shown in blue. Regarding government nodes, in the Montreal network, the smaller node represents the provincial government, while the larger node represents the federal government. In the Toulouse network, the smallest yellow node represents the regional government, the medium node represents the national government, and the largest node represents the EU supranational level.

We also conducted the analysis of centrality of actors in both ecosystems and Table 2 presents centrality scores for five most central actors. We use eigenvector centrality to evaluate the degree of embeddedness in our networks as this measure reflects the degree of connectivity to actors that are also highly connected and helps to identify the core members of the network (Gulati 2007).

Table 2: Eigenvector centrality scores of key actors and their collaborative linkages in the Montreal and Toulouse aerospace clusters.

Montreal		Toulouse	
Bombardier	0.337	Airbus	0.608
CAE	0.220	Regional government	0.532
Pratt and Whitney	0.187	ENAC	0.491
Bell Helicopter	0.133	National government	0.428
Thales	0.126	EU	0.412

The analysis reveals important differences in the structure of the networks. The Montreal network is mainly orchestrated by firms such as Bombardier, Pratt and Whitney Canada, Heroux Devtek, CAE, Bell Textron Canada and others. While the Consortium for Research and Innovation in Aerospace in Québec (CRIAQ), McGill University and Concordia University are also central nodes, the core of the network is dominated by a number of large and medium-sized private firms. At the same time, in the Toulouse network, the core is dominated by the three levels of government (the regional government, which supports and facilitates many projects; the national government, which supports inter-cluster projects within the country; and the EU, which initiates pan-European collaborative projects through research programs and regulations), research institutions and universities such as ENAC and ONERA, and Airbus. We validated the network diagrams and findings with the main firms of the ecosystems (when we conducted interviews, the analysis of which will be presented in the following section) to confirm that the data collection process was sufficiently complete and reliable.

We can see (Table 2) that the core actors in Toulouse network have higher centrality than Montreal actors, meaning that the overall network is more centralized around these actors. It is also important to note that Toulouse network is much denser and the activity in the network is organized into subclusters well-coordinated by the core actors. At the same time, Montreal's network is more organic and decentralized. It is clear from the diagram that collaborative structure in Toulouse is a very well-planned system and is primarily a top-down one where coordination is performed by the alliance of the multilevel government and Airbus, while in Montreal it is more bottom-up, organic and discontinued.

While both Montreal and Toulouse have established trade associations and industry groups to represent the interests of the aerospace sector at the national and

international levels, and these associations facilitate advocacy for favorable policies and contracts that enhance the competitiveness of the aerospace industry in their respective regions, there are important differences in the roles of the government. This role is crucial and inseparable for the Toulouse aerospace cluster, which has historically been shaped and orchestrated by public authorities (the French government, the EU administration, regional and local authorities) since its creation, while this role is more modest in the Montreal aerospace cluster, which was initially shaped by private initiatives from industrial firms. The government is only marginally involved in the network in Montreal's case and most of the relationships are supported and facilitated by private initiatives amplified by intermediaries such as CRIAQ. At the same time, this situation will most likely change soon, as in 2023 the Quebec government announced financial contributions totaling more than \$47.45 million to support mobilizing projects in the Québec aerospace industry in order to promote the development of new technologies related to the aircraft of tomorrow and sustainable mobility in aerospace.¹⁰ For this reason, the provincial government has made a major effort to support collaborative innovation for the advancement of Québec's aerospace industry, which has led to the launch of new major collaborative projects that will change the structure of the network. The new projects will link the various players in the ecosystem, increasing the overall density of the network and making it more cohesive. In addition, as the Quebec provincial government is behind these projects, its role in the network will increase, which will be reflected in the subsequent increase in its centrality score. In the spring of 2024, the government also designated Greater Montreal as an aerospace innovation zone called Espace Aero. At the same time, the Montreal aerospace cluster is urging the federal government to implement a national aerospace strategy to strengthen the country's industrial capacity and competitiveness.¹¹ Should both the Quebec and federal governments become more active in the network, it is possible that the Montreal network may become more akin to the Toulouse network over time.

In terms of international relations and knowledge exchange between the two aerospace clusters, the fact that some key designers and producers of aeronautical subsystems (Airbus, Thales, Safran, etc.) have production plants

and research units in both clusters facilitates the intensity of the link between the clusters and the production of externalities spillovers.

4.2 Analysis of interviews

The purpose of the interviews was to complement our social network analysis and to zoom in on key cases, providing further nuance and deeper insights. We conducted thematic coding (Gibbs 2007) of the information obtained from the interviews, focusing on two broad themes related to the transition to sustainability in both clusters: the role of key actors and their collaboration, and the role of governments and supportive policies. The interviews added a qualitative layer of data that allowed us to understand the contributions and experiences of each cluster, highlighting cluster-specific similarities and differences, as well as specific patterns, initiatives, or roles of key actors leading to sustainability efforts. Within these broad themes, we also identified sub-themes related to differences and similarities between clusters.

According to the interviews, while there are some similarities in the way the two respective clusters have responded to sustainability challenges, there are also significant differences, which are highlighted in the following section.

We interviewed actors from both clusters, which provided insights into collaboration within and across clusters, as well as the challenges and opportunities that can arise as sustainability transitions move between ecosystems. Our goal was to show how these common actors navigate different regional policies, industrial cultures, and resource configurations, thus revealing a more strategic view that might be obscured by a single cluster analysis.

We recognize that excluding cluster-unique actors may reduce the cluster-specific content, but this should not affect our main purpose, as we are interested in the comparative dynamics of sustainability transitions. As a result, we are able to highlight some of the overarching themes around collaboration and sustainability strategies that are relevant to both ecosystems.

5 Results and discussion

The network analysis and the interviews provide some important results for our research question, which focuses on understanding how the specific characteristics of aerospace clusters contribute to shaping the innovation dynamics of aircraft manufacturers in their efforts to meet the requirements of sustainable development. These

¹⁰ <https://www.aeromontreal.ca/quebec-government-announces-over-47-million-support-4-mobilizing-aerospace-projects.html>.

¹¹ <https://www.newswire.ca/news-releases/canada-s-2024-2025-budget-aero-montreal-lauds-the-government-efforts-and-emphasizes-the-importance-of-building-a-national-aerospace-strategy-885286373.html>.

findings can be grouped into three main categories: The first category (5.1) is on the role of the main aerospace firms and the new forms of collaboration between actors in the respective clusters, the second category (5.2) is on the role of governments and public authorities in supporting the transition to sustainability in each cluster, the third category (5.3) is on the specific role of some key actors to lead the change in the aerospace cluster:

5.1 The role of the main aerospace firms and the new forms of collaboration between the actors in the respective clusters

Regarding the main aerospace firms in the clusters and the efforts they have made in the process of transition to sustainability, in both clusters there have been significant internal innovative changes to adapt to the new context, in the form of new projects, new departments or new training programs aimed at improving the main components of an aircraft (engine, wings, materials, etc.) towards more sustainable results. Private sector representatives in both clusters argue that the transition to sustainability is closely linked to innovation and helps to increase profitability and efficiency: innovation outcomes simultaneously reduce costs, increase profitability and reduce the environmental footprint, so that innovation, sustainability and increased profitability go together. As one Airbus manager argued, “...when we innovate to burn less fuel and increase the durability of our systems and components, it simultaneously reduces our footprint and costs; therefore, profitability goes up”. As highlighted above, the fact that the same OEMs are present in both clusters explains some similarities between Toulouse and Montreal in the search for advanced innovations in many aircraft components. For each OEM, knowledge related to new innovative solutions would circulate very quickly across cluster boundaries.

Some interesting innovations in the various components of commercial aircraft can be highlighted in both clusters, with some nuances.

For example, aerospace firms in Montreal have developed a series of initiatives aimed at reducing carbon emissions, minimizing waste and optimizing energy use in the aerospace sector. As a result, several projects are being launched that focus on reducing CO₂ emissions through the implementation of state-of-the-art propulsion systems, aerodynamic design, and advanced technologies. According to a senior executive in Montreal, “...we have been true pioneers in aviation biofuels...we have also been leaders in hybrid electric engines and innovative aircraft configurations.” Another senior executive in Montreal

added, “...it's going to be the most important project [at Bombardier in terms of reducing CO₂ emissions] ... It involves numerous subcontractors and focuses on aerodynamics and platform configuration, which could achieve up to a 20 % reduction in emissions. In addition, we are looking at biofuels and potentially hydrogen to further reduce emissions. When the technologies are ready, hybrid electric configurations could also be incorporated ... this could result in an aircraft that produces 50 % less CO₂ than our current models”.

At the same time, Toulouse is becoming a focal point for numerous innovative efforts in the area of sustainability in aircraft production. One notable initiative is the development of electric two-seaters aircraft for training purposes, alongside plans to establish production lines for larger, more environmentally friendly regional aircraft. The head of a department at an academic institution in Toulouse said: “...Aura Aero is planning to launch an electric two-seater aircraft for training, which is fairly conventional. However, more notably, the firm is setting up a production line for a 19-seater aircraft in the CS23 [small aircraft certification training] category of light aviation, in order to develop commercial regional aviation.”

In both regions, dealing with such a disruptive context has led to an increase in new forms of collaboration between different actors (public organizations, government agencies, private organizations, industry associations, intermediary organizations, universities, scientific research institutions, and other types of organizations). As an example, a senior manager argued: “We (firms) realized that given the external pressures and challenges, we can no longer act in isolation, we need deep and broad collaboration across the cluster. For example, we started working a lot with our local supply chain. Other OEMs also became very proactive and we increasingly started to collaborate with them as well...”. These new forms of collaboration between aerospace cluster actors have led to the creation of many intermediary organizations, which are becoming key players in the current transformation of the economic and social regime. The interviewees mentioned that in Montreal, these collaborations were mainly led and orchestrated by private actors, while in the case of Toulouse, different levels of government and research institutions took the lead.

In Montreal, intermediary organizations such as GARDN (Green Aviation Research & Development Network), CRIAQ (Consortium for Research and Innovation in Aerospace in Québec), Aéro Montreal, AQA (Aviation Quality Assurance), SA2GE (Smart Affordable Green Efficient) or CAMAQ (Comité Sectoriel de main-d'oeuvre en Aérospatiale) play an important role in facilitating collaboration and information exchange within the cluster.

These intermediary organizations have also developed strong relationships with other provinces in Canada. For example, the genesis of GARDN can be traced back to an initiative led by the University of Toronto. As one executive noted, "...for GARDN, it was the aerospace industry that started it all. It was mainly executives from Pratt & Whitney, Bombardier, and CMC Electronics that got together [in Toronto] ... Of course it expanded there, in Montreal too, but paradoxically it was Toronto that had it".

In Toulouse, local research institutions have been more proactive. Aerospace firms and strong engineering schools have taken the lead in new collaborations such as Aerospace Valley or ISA (Institute for Sustainable Aviation). Engineering schools, in particular, play an important role in the local aerospace industry, especially by supporting smaller firms (SMEs) and involving them in various initiatives with larger firms. This highlights the importance of educational institutions in driving innovation within the Toulouse aerospace cluster. In other words, schools and local firms work together on research and development projects that drive progress in the industry.

5.2 The role of governments and public authorities in supporting the transition to sustainability in each cluster

The Toulouse aerospace cluster operates within a highly structured innovation ecosystem, characterized by extensive government intervention at multiple levels.¹² The French national government, the Occitanie regional government, and the European Union play a central role in funding aerospace R&D, coordinating strategic initiatives such as Aerospace Valley, and enforcing environmental regulations. These bodies also work with leading engineering schools such as ISAE-SUPAERO and ENAC to ensure a steady talent pipeline. This centralized, top-down approach ensures alignment with sustainability goals and fosters a cohesive innovation environment, but it has created a dependency

on government direction that can limit flexibility and the pursuit of disruptive innovation.

In contrast, the Montreal aerospace cluster follows a more decentralized, bottom-up model where government involvement is supportive but less directive. While the federal governments of Canada and the provincial government of Québec provide funding for selected initiatives such as GARDN and CRIAQ, they do not coordinate cluster-wide strategies or impose strict regulations. Collaboration is largely driven by private firms and academic institutions, with intermediary organizations such as Aero Montreal facilitating connections. This decentralized approach encourages experimentation and agility, but places greater responsibility on industry and academia to lead innovation, often resulting in fragmented efforts compared to the centralized orchestration seen in Toulouse.

Such a difference between Toulouse and Montreal leads to a paradoxical situation:

In Toulouse, the central role of public authorities in orchestrating the aviation ecosystem has clearly contributed to the cluster's aircraft manufacturers increasingly incorporating sustainable elements or subcomponents into commercial aircraft. However, this key role of public authorities also explains why no significant disruptive innovation has been achieved in the design and manufacture of aircraft in the cluster. The reason is that until the early 2020s, when public authorities mostly recommended industrial manufacturers to increase sustainable development, they did not impose strict regulations to drastically redesign aircraft. In the last two decades, as expressed by a top executive of Bombardier, "Airbus was in its mad race to lower prices with Boeing (which contributed to rigidify the classic design of "non-sustainable" aircraft before Covid)". So, following this competitive dynamic, Airbus, which was focused on price reduction, adopted incremental new developments in sustainability when they fit this strategy, but did not introduce disruptive changes that were considered too risky. For example, Airbus was able to introduce a more energy efficient engine in terms of engine components (while Boeing was mainly working on a more economical fuel during the same period).

In the Toulouse cluster, it was only after the challenges posed by the Covid-19 pandemic that European and French public authorities increasingly imposed strict public environmental regulations on aircraft manufacturers, such as the CLEANSKY initiatives, which significantly triggered disruptive innovations to meet sustainability challenges. For example, the priority given to sustainability in Toulouse has been reinforced by the creation in 2021 of the ISA (Institute for Sustainable Aviation), a leading collaborative structure

¹² France 2030 is a French national strategic plan that allocates €1.2 billion to develop the first low-carbon aircraft by 2030. Additionally, €200 million is dedicated to establishing production capabilities for Sustainable Aviation Fuels (SAF). Complementing this effort, Bpifrance Initiatives supports innovation and decarbonization in the aeronautics sector through thematic and general funding opportunities.

At the European level, Horizon Europe, the EU's flagship research and innovation program, funds transformative projects like Clean Aviation and SESAR. These initiatives aim to develop sustainable aviation technologies and modernize air traffic management systems. Within Horizon Europe, the Clean Aviation Joint Undertaking plays a critical role as a public-private partnership, advancing eco-friendly innovations such as hybrid-electric propulsion systems and lightweight materials (F.initiatives 2025).

promoting interdisciplinary research towards a sustainable future for aviation.

While in Montreal, in a loosely structured innovation system where the weight of the public authorities (especially the regulatory ones) is less strong, the interviews clearly insist on the fact that it was a group of passionate actors from industry and universities that were instrumental in orchestrating the disruptive innovations to meet sustainability challenges that led in particular to the production of the Bombardier C-Series. This group of diverse actors from different firms (Pratt & Whitney, Bombardier Aerospace, CMC Electronics, Bell Textron Canada, etc.), supported by aeronautics academics in Canadian developments (Polytechnique Montreal, ETS Montreal, Sherbrooke, Concordia, McGill and the University of Toronto), created a series of initiatives that contributed to position Canada as a leader in aerospace environmental research and development.

For GARDN it was the aerospace industry that is at the origin of all this [sustainable aerospace innovation]. There were people from mainly Pratt, Bombardier and CMC Electronics who had come together. And who seized the opportunity of a program [recognized and utilized the chance to access funding and resources] that was a new program: The Business-Led Networks of Centers of Excellence program of the federal government (former director of an important initiative in Montreal).

GARDN sought to promote the use of biofuels in aviation, improve the environmental impact of airports, and collaborate with international organizations to advance environmental progress in the aerospace sector. This initiative was followed by many others, benefiting from the group of passionate individuals from industry and academia who helped orchestrate the change towards sustainability in the cluster. The flexibility of the Montreal cluster has led to numerous initiatives and achievements, both in the field of

collective organizations and groups (CRIAQ, Aero Montreal, Caric, SA2GE, etc.) and in the private sector (C-Series) (see Table 3).

Government initiatives followed (though not always coordinated, especially between Quebec and Ontario and the federal government), and since public regulatory pressure on the environment is much less intense than in Europe, these initiatives (unlike in Toulouse) did not drive regime change.

The same group of passionate actors was also at the origin of the major changes towards sustainable development in the various private firms of the Montreal aerospace cluster, in particular in the production of the C Series program by Bombardier, where the group was very active in convincing the firm's top managers to build a revolutionary aircraft in terms of respect for sustainable goals. Unlike Airbus or Boeing, which until the crisis responded to environmental constraints by adding a few more sustainable subsystems to existing aircraft (turbofan engine for Airbus, more efficient fuel for Boeing), the C Series involved a complete forward-looking redesign of the aircraft concept. Powered by Pratt & Whitney geared turbofan engines, the C Series features a carbon composite wing, fly-by-wire controls, an aluminum-lithium fuselage and optimized aerodynamics for better fuel efficiency. This series of subsystems has evolved over the years to support aviation with a smaller carbon footprint. The C Series has been hailed as a flagship of Canadian innovation by launch operators, who have reported better-than-expected fuel burn and dispatch reliability, as well as by passengers, who have given unanimously positive feedback, and crew members, who have been enthusiastic about the aircraft's performance.

For Bombardier, however, the success of the C Series was fleeting. As Taylor (2022: p. 2) wrote, "the technological advance taken by Bombardier with the C Series was

Table 3: Breakdown of C-series types and their accomplishments.

C-series types	Key achievements
CS100	The A220-100 (previously known as the Bombardier CS100), part of the A220 family, is pivotal for airlines due to its focus on the 100–135 seat market, a crucial segment. Its efficiency stands out, boasting advanced tech for lower fuel consumption and emissions, reducing operating costs. With a range of 6,390 km, it suits short and medium-haul routes well. Passenger comfort is prioritized, offering spaciousness akin to widebody jets despite its single-aisle design, with ample storage and large windows. Its dimensions are optimized for maximizing space and accommodating 100–135 passengers, adaptable to various seating configurations. ^a
CS300	The A220-300 (previously known as the Bombardier CS300), part of the A220 family, is a significant advancement in aviation for several reasons. Tailored for the 120–160 seat market, it enables airlines to profitably serve previously challenging routes. Its capacity, ranging from 120 to 160 passengers, offers flexibility to meet varying market demands. With a range of 6,297 km and a maximum operating speed of M0.82, it facilitates efficient long-distance travel, aided by advanced aerodynamics. The cabin prioritizes passenger comfort with a spacious layout, while ample cargo capacity enhances versatility. With optimized weight specifications, the A220-300 ensures efficient operations and flexibility in payload and fuel capacity. ^b

^a<https://aircraft.airbus.com/en/aircraft/a220/a220-100>. ^b<https://aircraft.airbus.com/en/aircraft/a220/a220-300>.

considered by Airbus and Boeing as a major threat. In 2017, when the C Series appeared to be on the verge of breaking into the U.S. market, Boeing used Bombardier's ample government aid as evidence for an anti-dumping claim that temporarily imposed a 300 per cent tariff on the plane. The tariff was eventually overturned but, by then, the damage had been done". Unfortunately for Bombardier, despite the plane's obvious competitive advantages, the Montreal-based firm eventually sold the entire program to Airbus in July 2018, and the plane was renamed the A-220. As an engineer pointed out: *"Bombardier was at risk financially. That was one of the challenges we had with the program – customers were looking at whether the program would survive. Unfortunately, Bombardier had several programs in development that were late and over budget. That put them in a situation where they couldn't really sustain the cash flow even to support the program"*.

5.3 The specific role of some key actors in managing the transition to sustainable aerospace

The results of the study have highlighted that one of the main differences between Toulouse and Montreal is that while in Toulouse the transition to sustainability has been driven by government and public authority initiatives, in Montreal the evolution of the path towards a sustainability regime in the aerospace cluster is clearly the result of a "bottom-up" approach, mostly based on a collective emergence process, in which the characteristics of the new regime emerged and gradually evolved based on the multipolar interactions of different stakeholders, orchestrated since mid-2000 by a group of core orchestrators from private industry and academia.

Such a bottom-up approach, orchestrated by a group of passionate people, can be interpreted as the construction of an 'innovation commons', a concept that has been highlighted in recent articles in ZFW – Advances in Economic Geography (Cohendet et al. 2021; Grandadam et al. 2022). The innovation commons is defined as the result of collective action that aims to contribute to the creation of an innovation resource pool in order to reduce uncertainty in the processes surrounding an emerging technology (Allen and Potts 2015, 2016; Potts 2018). Allen and Potts argue that the impetus for this industrial dynamic can be linked to self-organizing groups of technology enthusiasts who develop effective governance mechanisms for pooling distributed information resources. Following Oström, Allen and Potts (2016) refer to these groups of enthusiasts as "commoners" (those who manage common goods). Following Potts and Allen's contribution, a number of recent works on the orchestration

of complex ecosystems (Cohendet 2022; Sultana et al. 2023) have shown that industrial dynamics orchestrated by "commoners" result from the following sequence of innovation commons: (1) social commons, where the group of enthusiasts gradually develops and enriches a reservoir of resources in the form of a critical mass of social relationships, shared expertise and knowledge (who shares the same interest, who has the skills, who knows, who can help, etc.); (2) symbolic commons, which express the community's main challenges, purpose and shared values, and the intention to put these values into action in order to create an environment conducive to innovation; and (3) knowledge commons, which pool distributed information about knowledge, uses, costs, problems and market opportunities. This is also consistent with a recent study by Li et al. (2022), which showed that distributed network-based cluster structures are more resilient and conducive to innovation.

However, as we saw above, despite the aircraft's obvious competitive advantages, the Montreal-based firm ultimately sold the entire concept to Airbus in July 2018, and the aircraft was renamed the A-220. As one Airbus Canada executive points out, *"This is a change in leadership. I see it now as Airbus taking the lead on sustainability rather than Bombardier, which was the leader in the earlier years. It's not just Airbus Canada, but the entire Airbus Group that has made sustainable development a priority"*.

The sale of the program to Airbus was a major milestone, bringing Airbus to Montreal's aerospace cluster. It was not political mandates or the importance of the Canadian market that brought Airbus to Canada, but the opportunity to reclaim a program that Airbus (focused on its price-cutting competition with Boeing) could not develop earlier in Toulouse. As for Bombardier, all that remains of the once-mighty transportation conglomerate is a smaller but profitable business jet business.

At first glance, the story of the evolution of the C Series into the A-220 could be interpreted as an aggressive takeover of the Montreal-based aerospace giant by the Toulouse firm. There is no denying that Airbus in Toulouse has benefited greatly from the acquisition of Bombardier's C Series program in Montreal. The A-220 represents the integration of many cutting-edge technological innovations for a more sustainable aerospace industry, and the A220 family is already playing a key role in Airbus' commitment to its decarbonization goals and the transfer of efficient sustainable solutions from the former C Series to other aircraft designed and produced in Toulouse. For example, the fuel-efficient aircraft can already fly on a blend of up to 50 % Sustainable Aviation Fuel (SAF) and, like all other Airbus commercial aircraft, will be certified for 100 % SAF capability by 2030.

For Canada, the story of the C Series could be seen as another example of the “Canadian paradox”: while significant ideas and innovations are taking place in Canada, the same level of commercialization and ownership of these innovations is not observed in Canada compared to other countries, and in this perspective of commercialization and ownership, the level of support from Canadian government agencies is much lower than in the French counterpart, for example.

However, the evolution of the relationship between the two aerospace clusters can be interpreted in a much more positive light. The integration of the C Series program into Airbus has not only accelerated its commercialization but has also opened and expanded collaborative networks between specialists in Montreal and Toulouse. For example, the interviews we conducted for this study revealed in-depth discussions, knowledge sharing and mutual respect between members of CRIAQ or SA2GE on the one hand and members of Aerospace Valley and Pegase on the other.

Even if more complementarities between the two clusters need to be found and strengthened, we can already observe an increasing form of cooperation and collaboration between the two clusters. First of all, the cooperation between the two clusters has not only always existed, but has strongly increased over the years, as many industrial players are present in both clusters (such as Thales, Safran, Pratt & Whitney, CAE, etc.). Not only is there a constant exchange of knowledge and ideas, but the two clusters also share common goals and efforts, drawing on the expertise accumulated in Montreal to find new solutions for sustainability. Second, Airbus has become a key player in the Montreal aerospace cluster, not only by tapping into local human resources, but also by increasing its investment in local infrastructure and knowledge-sharing networks. In terms of federal infrastructure, Airbus has significantly increased its presence in Canada, covering the commercial aircraft, rotorcraft, defense and space sectors. Third, one of the lessons learned by the Canadian government from the C Series experience is that in its 2022 budget, the federal government announced plans to create an Innovation and Investment Agency to facilitate the more efficient introduction of innovative new ideas into the marketplace. The government also announced a review of the broad-based tax credit system to provide more targeted support for greater effectiveness.

[Correction added May 12, 2025 after online publication March 3, 2025: duplicate text has been removed]

6 Conclusions

The objective of this paper was to examine how aerospace clusters manage the environmental transition to achieve sustainability. To this end, the analysis was conducted on two major aerospace clusters, Montreal and Toulouse. By intersecting the economic geography and innovation literatures, we have proposed a conceptual framework regarding the conditions that facilitate such a transition. The empirical study has highlighted some significant differences between these two clusters in addressing the need to develop a sustainable aerospace industry: While in Toulouse the transition towards sustainability is a top-down approach orchestrated by the crucial role of public authorities, in Montreal the transition is a bottom-up one initiated by an active group of actors from aerospace firms and university research centers. The specific case of the C Series, a highly eco-efficient and innovative aircraft developed by Bombardier but eventually acquired by Airbus, revealed paradoxical results of cooperation and competition between the two aerospace clusters in this process of environmental transition. While the Airbus acquisition of the Bombardier C Series could have been interpreted as an aggressive form of FDI, a more careful analysis underscores the complementarity of the two sites in terms of their assets and capabilities for knowledge generation and value creation in the quest for sustainability. On the one hand, the Toulouse aerospace cluster benefits from the unique experience of Montreal firms and institutions in the field of sustainable aerospace; on the other hand, the Montreal aerospace cluster benefits from the arrival of a major player in the form of Airbus, which is increasingly investing in local infrastructures and research, thus reinforcing the strength and attractiveness of the cluster. Future studies could extend our analysis to clusters in other industries and use our approach to investigate how different structural and relational characteristics of clusters affect their performance.

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Informed consent: Not applicable.

Author contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission. Ekaterina Turkina conducted the network analysis and wrote up the network analysis part of the paper and parts of the methodology section. She also contributed to the analysis of interviews and the write-up of the interview analysis part, as well as helped with paper editing and paper revisions. Hassan Pishdadian contributed to the part of literature review section. He also conducted part of the interviews and part of the interview analysis section. In addition, he assisted in revising and editing the

paper. Alain Aubertin contributed to designing and securing interviews. He also contributed in main findings and discussion parts. In addition, he assisted in revising the paper. Laurent Simon contributed to the overall design of the paper and participated to the interviews. He also collaborated to the analyses and discussion, and to writing, revising, and editing. Patrick Cohendet contributed to the structure of the paper, participated to the interviews, and collaborated to the writing of the discussion and conclusion.

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Research funding: None declared.

Data availability: Not applicable since the data is confidential.

Appendix

List of the major data sources

<https://data.bloomberg.com/>.
<https://csimarket.com/index.php>.
<https://www.crunchbase.com/organization/spiderbook>.
<https://www.aeromontreal.ca/>.
http://www.montrealinternational.com/business-map/map/?companysearch=&chk_sector%5B%5D=1&chk_sector%5B%5D=31&chk_sector%5B%5D=9&chk_sector%5B%5D=24&chk_sector%5B%5D=8&chk_sector%5B%5D=6&chk_sector%5B%5D=7.
<http://www.aeromotion.ca/>.
<http://www.airdata.ca/about-us/partners/>.
<https://www.prattwhitney.com/en>.
<https://aiac.ca/members/bell-helicopter-textron/>.
<https://www.cae.com/civil-aviation/locations/cae-montreal/>.
<https://bombardier.com/en>.
<https://sciencebusiness.net/network-updates/polytechnique-montreal-partners-quebec-aerospace-innovation-hub>.
<https://www.mcgill.ca/miae/>.
<https://www.etsmtl.ca/en/research/our-research-directions/aeronautics-aerospace>.
<https://www.concordia.ca/ginacody/ciadi/about/partnerships.html>.
<https://www.criaq.aero/en/>.
<https://www.aerospace-valley.com/en>.
<https://www.toulouse-aerospace.fr/>.
<https://profile.clustercollaboration.eu/profile/cluster-organisation/05d81e4d-2e13-4681-a69a-ad9e9c604a88>.
<https://www.enac.fr/en>.

<https://www.onera.fr/en>.
<https://www.cnrs.fr/fr/personne/toulouse>.
<https://www.airbus.com/en>.
<https://www.ipsa.fr/entreprise/partenaires-ecole-ingenieur/>.
<https://www.isae-superaero.fr/en/about-isae-superaero/companies/isae-superaero-partner-companies/>.
<https://www.thalesgroup.com/en/countries/europe/thales-france>.
<https://www.atr-aircraft.com/presspost/the-french-government-the-occitanie-region-toulouse-blagnac-airport-airbus-atr-and-aerospace-valley-commit-to-develop-sustainable-aviation-fuel-in-occitanie/>.
https://www.isc.hbs.edu/Documents/resources/courses/moc-course-at-harvard/pdf/student-projects/France_Aerospace_2013.pdf.
<https://www.eacp-aero.eu/projects/care.html>.
<https://www.clustercollaboration.eu/tags/cluster-mapping-tool>.
https://single-market-economy.ec.europa.eu/industry/cluster-policy_en.
<https://reporting.clustercollaboration.eu/>.
https://02cecbc4.sibforms.com/serve/MUIEAHbLJQS_znM1suDNDr9ZS2Ka5ODbIQ8tf3Dvkws02dAkYjb2GdYsF-JEQlHsR3sxpHsmwPx1p2dQUO3lfBrlaA89_Io_I8Q6lQk_2wmupIUo19BfG1bVliYS5dPUNM3jf_jh3Q4zVcAZbgUNGk3nX4h_a0hVz8NtpY7V67DYyJNkPJS7E84_h81WIqEZcsIsdnIQNhDEWT.

References

- Åkerman, J. (2005). Sustainable air transport — on track in 2050. *Transp. Res. D: Transp. Environ.* 10: 111–126.
- Allen, D.W. and Potts, J. (2015). The innovation commons—why it exists, what it does, who it benefits, and how. *What it Does, Who it Benefits, and How* (June 11, 2015).
- Allen, D.W. and Potts, J. (2016). How innovation commons contribute to discovering and developing new technologies. *Int. J. Commons* 10: 1035–1105.
- Bathelt, H. and Li, P. (2020). Processes of building cross-border knowledge pipelines. *Res. Policy* 49: 103928.
- Bouckaert, S., Pales, A.F., McGlade, C., Remme, U., Wanner, B., Varro, L., and Spencer, T. (2021). *Net zero by 2050: a roadmap for the global energy sector*. International Energy Agency (IEA), Paris, France, pp 83–99. Available at: <https://iea.blob.core.windows.net/assets/063ae08a-7114-4b58-a34e-39db2112d0a2/NetZeroBy2050-ARoadmapfortheGlobalEnergySector.pdf>.
- Bozdogan, K., Deyst, J., Hoult, D., and Lucas, M. (1998). Architectural innovation in product development through early supplier integration. *R&D Manag.* 28: 163–173.
- Bravo, A., Vieira, D., and Ferrer, G. (2022). Emissions of future conventional aircrafts adopting evolutionary technologies. *J. Clean. Prod.* 347: 131246.

- Broekel, T. and Boschma, R. (2012). Knowledge networks in the Dutch aviation industry: the proximity paradox. *J. Econ. Geogr.* 12: 409–433.
- Cohendet, P. (2022). Architectures of the commons: collaborative spaces and innovation. *ZFW — Adv. Econ. Geogr.* 66: 36–48.
- Cohendet, P., Grandadam, D., and Suire, R. (2021). Reconsidering the dynamics of local knowledge creation: middlegrounds and local innovation commons in the case of FabLabs. *Z. Wirtschaftsgeogr.* 65: 1–11.
- Dias, V.M.R., Jugend, D., de Camargo Fiorini, P., do Amaral Razzino, C., and Pinheiro, M.A.P. (2022). Possibilities for applying the circular economy in the aerospace industry: practices, opportunities and challenges. *J. Air Transport. Manag.* 102: 102227.
- Emilien, B., Lévesque, C., Morissette, L., and Perez-Lauzon, S. (2019). La contribution des institutions régionales à la gestion des talents: regards sur la grappe aérospatiale de Montréal. *Relat. Ind./Ind. Relat.* 74: 473–497.
- Evers, H.D., Gerke, S., and Menkhoff, T. (2010). Knowledge clusters and knowledge hubs: designing epistemic landscapes for development. *J. Knowl. Manag.* 14: 678–689.
- F.initiatives (2025). L'innovation dans l'aéronautique. F.initiatives, Available at: <https://www.f-initiatives.com/>.
- Flaherty, G.T. and Holmes, A. (2020). Will flight shaming influence the future of air travel? *J. Trav. Med.* 27: taz088.
- Fortunato, S. (2010). Community detection in graphs. *Phys. Rep.* 486: 75–174.
- Galvin, P. (2019). Local government, multilevel governance, and cluster-based innovation policy: economic cluster strategies in Canada's city regions. *Can. Public Adm.* 62: 122–150.
- Gambardella, A. and McGahan, A. M. (2010). Business-model innovation: general purpose technologies and their implications for industry structure. *Long Range Plan.* 43: 262–271.
- Gangi, F., Mustilli, M., Daniele, L.M., and Coscia, M. (2022). The sustainable development of the aerospace industry: drivers and impact of corporate environmental responsibility. *Bus. Strat. Environ.* 31: 218–235.
- Gardes, N., Dostaler, I., Barredy, C., and Gourmel-Rouger, C. (2015). Aerospace clusters and competitiveness poles: a France-Quebec comparison. *J. Traffic Transport. Eng.* 3: 52–62.
- Gibbs, G.R. (2007). Thematic coding and categorizing. *Anal. Qual. Data* 703.
- Gostic, W.J. (1998). *Aerospace supply chain management*, Doctoral dissertation. Massachusetts Institute of Technology.
- Grandadam, D., Cohendet, P., and Suire, R. (2022). Building and nurturing grassroots innovation: a policy framework based on the local commons. *Eur. Plan. Stud.* 30: 1577–1595.
- Gray, M., Golob, E., and Markusen, A. (1996). Big firms, long arms, wide shoulders: the 'hub-and-spoke' industrial district in the Seattle region. *Reg. Stud.* 30: 651–666.
- Gulati, R. (2007). *Managing network resources: Alliances, affiliations, and other relational assets*. Oxford University Press, USA.
- Hallstedt, S.I., Bertoni, M., and Isaksson, O. (2015). Assessing sustainability and value of manufacturing processes: a case in the aerospace industry. *J. Clean. Prod.* 108: 169–182.
- Hansmann, R. and Binder, C.R. (2021). Reducing personal air-travel: restrictions, options and the role of justifications. *Transp. Res. D: Transp. Environ.* 96: 102859.
- Hassen, T.B., Klein, J.L., and Tremblay, D.G. (2012). Interorganizational relations, proximity, and innovation: the case of the aeronautics sector in Montreal. *Can. J. Urban Res.* 21: 52–78.
- Hickie, D. (2006). Knowledge and competitiveness in the aerospace industry: the cases of Toulouse, Seattle and North-west England. *Eur. Plan. Stud.* 14: 697–716.
- ICAO (2013). The challenges for the development and deployment of sustainable alternative fuels in aviation: Outcomes of ICAO's SUSTAF Experts Group. ICAO. Available at: https://www.icao.int/environmental-protection/GFAAF/Documents/ICAO%20SUSTAF%20experts%20group%20outcomes_release%20May2013.pdf.
- ICAO (2022a). Innovation for a green transition: 2022 environmental report. ICAO. Available at: <https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2022/ICAO%20ENV%20Report%202022%20F4.pdf>.
- ICAO (2022b). Special supplement on long-term aspirational goal (LTAG): 2022 environmental report. ICAO. Available at: https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2022/ENVReport2022_Special%20Supplement%20on%20LTAG.pdf.
- Kitajima, M. (2020). Mechanism of triple helix circulation, cluster-engine, and cluster-reactor: a case study on greater-montreal aerospace cluster. *Mach. Econ. Res.* 27–40.
- Kivimaa, P., Boon, W., Hyysalo, S., and Klerkx, L. (2019). Towards a typology of intermediaries in sustainability transitions: a systematic review and a research agenda. *Res. Policy* 48: 1062–1075.
- Li, P., Turkina, E., and Van Assche, A. (2022). The tortoise and the hare: industry clockspeed and resilience of production and knowledge networks in Montreal's aerospace industry. *ZFW — Adv. Econ. Geogr.* 66: 81–95.
- Lorenzen, M. and Mudambi, R. (2013). Clusters, connectivity and catch-up: bollywood and Bangalore in the global economy. *J. Econ. Geogr.* 13: 501–534.
- Malmberg, A. and Maskell, P. (2002). The elusive concept of localization economies: towards a knowledge-based theory of spatial clustering. *Environ. Plann. A: Econ. Space* 34: 429–449.
- Malmberg, A. and Power, D. (2005). (How) do (firms in) clusters create knowledge? *Ind. Innov.* 12: 409–431.
- Maskell, P., Bathelt, H., and Malmberg, A. (2004). Temporary clusters and knowledge creation: the effects of international trade fairs, conventions and other professional gatherings. *Paper presented to the 100th Annual Meeting of the Association of American Geographers, March 14–19, Philadelphia*.
- Millar, J. and Salt, J. (2008). Portfolios of mobility: the movement of expertise in transnational corporations in two sectors — aerospace and extractive industries. *Glob. Netw.* 8: 25–50.
- Niosi, J. and Zhegu, M. (2005). Aerospace clusters: local or global knowledge spillovers? *Ind. Innov.* 12: 5–29.
- Niosi, J. and Zhegu, M. (2010). Anchor tenants and regional innovation systems: the aircraft industry. *Int. J. Technol. Manag.* 50: 263–284.
- Overton, J. (2022). The growth in greenhouse gas emissions from commercial aviation. The Environmental and Energy Study Institute (EESI), Available at: https://www.eesi.org/files/IssueBrief_Climate_Impacts_Aviation_2019rev2022.pdf.
- Paone, M. (2016). Aerospace clusters. *World's Best Practice and Future Perspectives. An Opportunity for South Australia*.
- Porter, M.E. and Takeuchi, H. (2010). *Microeconomics of competitiveness: Aerospace cluster in the Toulouse region*. Harvard Business School, Boston, MA.

- Potts, J. (2018). Governing the innovation commons. *J. Inst. Econ.* 14: 1025–1047.
- Stephenson, A. (2024). Transformation of Canada's fighter capability: a generational perspective. *J. Mil. Strateg. Stud.* 23.
- Sultana, N., Turkina, E., and Cohendet, P. (2023). The mechanisms underlying the emergence of innovation ecosystems: the case of the AI ecosystem in Montreal. *Eur. Plan. Stud.* 31: 1443–1465.
- Taylor, P. (2022). *Bombardier's C-series is a huge hit...for Airbus*. CPA, Available at: <https://www.cpacanada.ca/news/pivot-magazine/bombardier-canadian-innovation>.
- Turkina, E., Van Assche, A., and Kali, R. (2016). Structure and evolution of global cluster networks: evidence from the aerospace industry. *J. Econ. Geogr.* 16: 1211–1234.
- Undavalli, V., Olatunde, O.B.G., Boylu, R., Wei, C., Haeker, J., Hamilton, J., and Khandelwal, B. (2023). Recent advancements in sustainable aviation fuels. *Prog. Aero. Sci.* 136: 100876.
- Viswanathan, V., Epstein, A.H., Chiang, Y.M., Takeuchi, E., Bradley, M., Langford, J., and Winter, M. (2022). The challenges and opportunities of battery-powered flight. *Nature* 601: 519–525.
- Yilmaz, N. and Atmanli, A. (2017). Sustainable alternative fuels in aviation. *Energy* 140: 1378–1386.