WIPO Technology Trends

Technical Annex

Future of Transportation in the Air

WIPO

World Intellectual Property Organization
34, chemin des Colombettes, P.O. Box 18
CH-1211 Geneva 20, Switzerland

wipo.int

DOI: 10.34667/tind.57971

Cover: Getty Images / KrisCole,
pariwat pannium

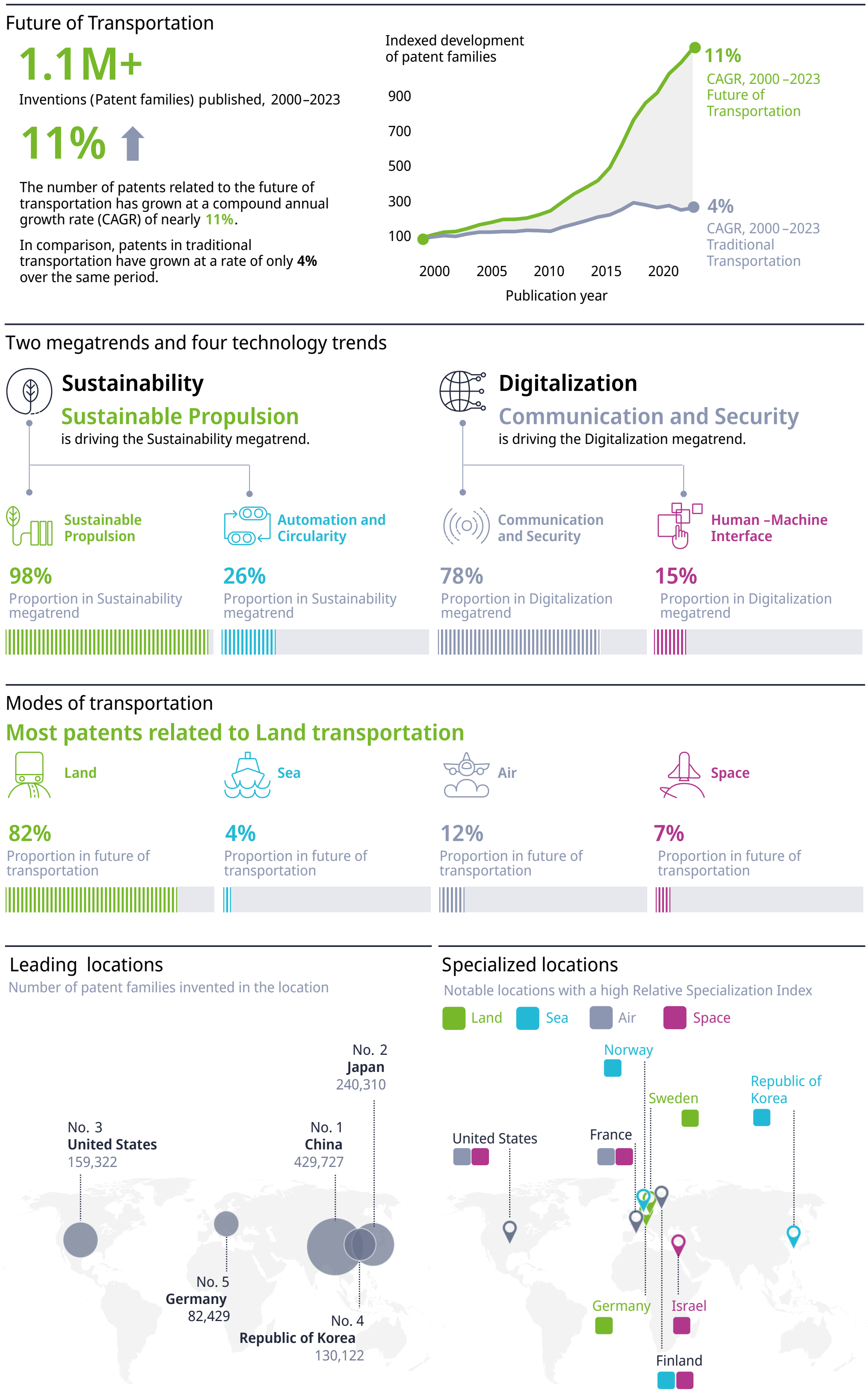
Table of contents

Introduction to air transportation

This technical annex to the WIPO Technology Trends Report on the Future of Transportation provides an in-depth analysis of air transportation, focusing on global patenting trends that reveal key technological advancements within the aviation industry. By examining extensive patent data, this annex uncovers insights into the innovations transforming air transport, including developments in aircraft design, propulsion systems, safety and control technologies, and sustainable aviation solutions. Full details on the research methodology and different patent indicators used can be found in the Appendix to the report.

It explores emerging technologies such as electric and hybrid propulsion, autonomous flight systems, lightweight materials and advanced aerodynamics, as well as digital transformations in areas like air traffic management, smart airports, and predictive maintenance. This analysis highlights the key players, geographic trends, and technology hotspots shaping the industry's future, while also considering the impact of regulatory changes and environmental challenges on innovation. Designed as a comprehensive resource for industry stakeholders, policymakers, researchers and innovators, this annex offers valuable foresight into the future of aviation technology and its potential to meet the evolving demands for efficiency, safety and environmental sustainability in global air travel.

Figure C1 Exploring the main findings of the WIPO Technology Trends report on the Future of Transportation



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Overview of air transportation

Air transportation involves the movement of people, goods and animals through the atmosphere, primarily using airplanes and helicopters. [1] It encompasses various aircraft types, including commercial airliners, cargo planes and private jets, and relies on infrastructure such as airports, air traffic control systems and aviation security measures. [2] This mode of transportation has evolved from early experimental flights to modern, technologically advanced systems, playing a crucial role in facilitating global travel, commerce and economic activities.

Air transportation is indispensable for the overall transportation system, because of its speed and ability to cover long distances quickly, making it a vital link in international trade and travel. [3] Unlike land and sea transport, which are limited by geographical barriers, air transport can directly connect remote regions and major economic hubs, fostering global connectivity. This makes it essential for providing rapid transit, which is critical for both business and leisure travel, as well as for the timely delivery of high-value and perishable goods. [4] Thus, air transport often acts as a facilitator for other modes of transportation, ensuring the swift movement of goods and passengers across continents. [5] For instance, goods transported by sea or land are often transferred to their final destination by air, especially when time is a critical factor. Similarly, passengers traveling internationally rely on air transportation for the main legs of their journeys.

Air transportation plays a crucial role in global trade and passenger mobility, influencing both economic development and international relations. [6] Passenger travel activity is expected to grow significantly, with worldwide passenger kilometers nearly double between 2019 and 2050 under the Current Ambition scenario. [7] This highlights the an increasing demand for air travel, driven by economic growth, particularly in emerging markets. [8]

Air transport's share of CO_2 emissions is significant and expected to increase under current policies. In 2022, air transport accounted for 2% of global CO_2 emissions. [9] By 2050, under the Current Ambition scenario, aviation emissions will constitute a larger share of total emissions, despite technological advancements and efficiency improvements. Even under the High Ambition scenario, where total emissions are reduced significantly, aviation emissions will still be a major concern. [10]

Efforts to decarbonize the air transport sector are critical for reducing emissions and achieving sustainable mobility. This includes adopting sustainable aviation fuels, improving aircraft efficiency and implementing policies that encourage the use of cleaner technologies. These measures will help create a more sustainable and efficient transportation system, capable of meeting future demand while minimizing environmental impacts, according to BCG [11] and the IEA. [12]

Sustainability and digitalization are two megatrends that have a vital role to play in transforming the future of air transportation. A focus on sustainability drives innovation toward reducing CO_2 emissions and promoting greener practices. Meanwhile, digitalization enhances

1 Tiwari, P., P. Yadav, S. Kumar, B. K. Mishra, G. N. Nguyen, S. P. Gochhayat et al. (2018). Sentiment analysis for airlines services based on Twitter dataset. Social Network Analytics: Computational Research Methods and Techniques, 149, 194-213.
2 Wensveen, J. (2023). Air Transportation: A Global Management Perspective. Routledge.
3 Tiwari, P., P. Yadav, S. Kumar, B. K. Mishra, G. N. Nguyen, S. P. Gochhayat et al. (2018). Sentiment analysis for airlines services based on Twitter dataset. Social Network Analytics: Computational Research Methods and Techniques, 149, 194–213.
4 Guimera, R., S. Mossa, A. Turtschi and L. N. Amaral (2005). The worldwide air transportation network: Anomalous centrality, community structure, and cities' global roles. Proceedings of the National Academy of Sciences, 102(22), 7794–7799.
5 Hettiarachchi, L. (2020). International Air Transport Association (IATA): Structure and Legitimacy of Its Quasi International Regulatory Power. The Hague: Eleven International Publishing, 1–258.
6 World Bank (2024). Brief: Air Transport. World Bank Group. Available at: www.worldbank.org/en/topic/transport/brief/airtransport.
7 ITF (2023). ITF Transport Outlook 2023: Summary. Paris: OECD Publishing.
8 IATA (2023). Global Outlook for Air Transport: A Local Sweet Spot. International Air Transport Association. Available at: www.iata.org/en/iata-repository/publications/economic-reports/global-outlook-for-air-transport---december-2023---report.
9 IEA (2022). Tracking aviation. International Energy Agency. Available at: www.iea.org/energy-system/transport/aviation.
10 ITF (2023). ITF Transport Outlook 2023: Summary. Paris: OECD Publishing.
11 BCG (2021). Plotting aviation’s uncharted course to net zero. Boston Consulting Group. Available at: www.bcg.com/publications/2021/net-zero-aviation-is-the-future-of-aviation.
12 IEA (2022). Tracking aviation. International Energy Agency. Available at: www.iea.org/energy-system/transport/aviation.

operational efficiency through advancements in technology and data analytics, making aviation systems smarter and more adaptive to future challenges.

The International Air Transport Association (IATA) has highlighted the need for ambitious policies in order to achieve significant reductions in aviation emissions, projecting that CO_2 emissions from aviation could be cut by up to 50% by 2050 with the right measures in place. [13] The International Civil Aviation Organization (ICAO) also emphasizes the potential of accelerating the transition to sustainable aviation fuels (SAFs) and implementing efficiency technologies for both commercial and cargo aircraft to achieve significant emission reductions. [14] These commitments reflect a concerted effort by global organizations to address the climate impact of the aviation sector.

Digitalization is revolutionizing the air transport sector by driving significant advancements in efficiency safety, and customer experience. Digital transformation is of high strategic importance in maintaining a competitive edge. Digital tools and technologies are streamlining operations, reducing costs and improving service delivery. For instance, operational cost reductions of up to 20% have been reported, showcasing the tangible benefits of adopting digital solutions. [15] Additionally, smart logistics solutions optimize supply chains, reducing waste and improving logistical efficiency.

Sustainable Propulsion technologies are transforming both passenger and freight air transportation:

– **Efficient aircraft turbines:** Advancements in turbine technology aim to improve fuel efficiency, reduce emissions and lower noise levels, contributing significantly to environmental sustainability.
– **Sustainable aviation fuels (SAFs)** is a cornerstone of a more Sustainable Propulsion, offering significant reductions in CO_2 emissions compared to traditional jet fuel. The International Energy Agency's (IEA) Aviation Outlook highlights that the adoption of SAFs is accelerating globally, driven by advancements in production technologies and increased availability. [16] SAFs are derived from renewable sources, such as plant oils, waste oils and other bio-based materials, and can be used in existing aircraft engines with minimal modifications.
– **Battery-based electric and/or hybrid aircraft** represent a promising solution for short-haul and regional flights, offering zero or lower tailpipe emissions and lower operating costs. [17] These aircraft are powered by electric motors and advanced battery technologies, which are continually improving in terms of energy density and charging times.
– **Hydrogen-powered aircraft** are emerging as a potential solution for long-haul flights and heavy-duty applications. [18] Hydrogen can be used in fuel cells to generate electricity or burned in modified jet engines. This technology offers the potential for zero-emission flights, with water vapor being the only byproduct. The U.S. National Blueprint for Transportation Decarbonization emphasizes that hydrogen-powered aircraft are ideal for applications requiring a longer ranges and a higher payloads. [19]

Automation and Circularity technologies are promoting efficient material use, smart production and enhanced recycling practices.

– **Efficient material use** is a key component of the circular economy, aiming to minimize waste and maximize resource efficiency. This involves adopting lightweight materials, utilizing advanced manufacturing techniques to reduce material waste, and designing aircraft for

13 IATA (2021). Our commitment to fly net zero by 2050. International Air Transport Association. Available at: www.iata.org/en/programs/environment/flynetzero.
14 European Commission (2024): EU and ICAO strengthen commitment to global aviation safety, security, and sustainability,. Available at: https://transport.ec.europa.eu/news-events/news/eu-and-icao-strengthen-commitment-global-aviation-safety-security-and-sustainability-2024-06-27_en.
15 Bain (2020). Digital operations: Don't depart without a strategy. Bain & Company. Available at: www.bain.com/insights/digital-operations-dont-depart-without-a-strategy.
16 IEA (2023). Aviation. International Energy Agency. Available at: www.iea.org/energy-system/transport/aviation.
17 WEF (2022). Target True Zero: Unlocking Sustainable Battery and Hydrogen-Powered Flight. World Economic Forum. Available at: www3.weforum.org/docs/WEF_Target_True_Zero_Aviation_ROUND_2022.pdf.
18 Yusaf, T., A. S. F. Mahamude, K. Kadirgama, D. Ramasamy, K. Farhana, H. A. Dhahad and A. R. A. Talib (2023). Sustainable hydrogen energy in aviation: A narrative review. International journal of hydrogen energy.
19 Department of Energy (2023). The U.S. National Blueprint for Transportation Decarbonization: A Joint Strategy to Transform Transportation. Available at: www.energy.gov/sites/default/files/2023-01/the-us-national-blueprint-for-transportation-decarbonization.pdf.

disassembly and recycling.[20] These practices ensure that materials are used optimally throughout the product lifecycle, reducing environmental impact and conserving resources.
- **Smart production and robotics** are transforming manufacturing processes by enhancing efficiency, precision and flexibility.[21] Advances in Industry 4.0 technologies, such as internet of things (IoT), machine learning, and cyber-physical systems, are enabling autonomous production lines that able to adapt to real-time data and optimize operations. Thus, smart production systems can significantly reduce waste, improve product quality, and enable predictive maintenance, thereby extending the lifespan of machinery and equipment. Robotics plays a crucial role in automating repetitive tasks, improving accuracy and reducing human error, all of which contribute to more sustainable manufacturing processes.
- **Recycling** is a fundamental aspect of the circular economy, aiming to recover valuable materials from end-of-life products and reintroduce them into the production cycle. The Green.org emphasizes in an article the importance of intelligent automation in enhancing recycling processes, such as sorting and processing recyclables more efficiently.[22] Innovative technologies like artificial intelligence (AI) and robotics are being used to improve the accuracy and efficiency of recycling operations, ensuring that more materials and components from an aircrafts such as engines, avionics and landing gear are recovered and reused.

Communication and Security technologies are paving the way for a new era of air transportation:

- **Navigation technologies such as advanced Air Traffic Management (ATM) Systems** are becoming increasingly essential for both passenger and freight transport. Such systems leverage real-time data, advanced routing algorithms, and AI to optimize flight paths, reduce delays and improve fuel efficiency. Consulting reports from McKinsey emphasize that the integration of AI into ATM systems is transforming route planning by predicting traffic patterns and suggesting alternative routes in real-time.[23]
- **Device-to-device technology** enhances communication between various systems and devices within the aviation ecosystem.[24] Such technology enables seamless data exchange between aircraft, ground control, maintenance systems, and passenger devices, improving operational efficiency and safety. By facilitating real-time information sharing, device-to-device communication helps in proactive maintenance, better passenger service and more efficient flight operations. According to industry experts, integrating device-to-device technology into the aviation sector can significantly reduce delays and improve the overall travel experience.[25]
- **Adoption of cloud computing and low latency internet** is revolutionizing how data is managed and utilized in air transportation. Cloud platforms enable the collection, storage and analysis of vast amounts of data from connected aircraft and infrastructure. According to Ericsson, low latency internet, particularly through 5G networks, facilitates real-time communication between aircraft and air traffic control systems.[26]
- **Cybersecurity of paramount concern, as air transportation becomes more digitalized.** Protecting aviation networks from cyber threats is essential to in ensuring safety and reliability for both passenger and freight transport. McKinsey's analysis points out that the rise in digital technologies has made aviation systems more vulnerable to cyberattacks, emphasizing the need for robust cybersecurity measures.[27] Such measures include encryption, secure communication protocols, and continuous monitoring to detect and mitigate potential threats.

20 Castillo Malagón, R., M. A. Cruz Reyes and R. S. Romero Saldaña (2024). Circular economy: A technological innovation strategy for sustainability in air transport. Mercados y negocios, 25(52), 31–52.
21 Aydın, S. and C. Kahraman (2021). Aviation 4.0 revolution. In Intelligent and Fuzzy Techniques in Aviation 4.0: Theory and Applications. Cham: Springer International Publishing, 3–19.
22 Green.org (2024). How AI is revolutionizing recycling processes. Available at: https://green.org/2024/01/30/how-ai-is-revolutionizing-recycling-processes.
23 McKinsey (2023). The promise of travel in the age of AI. McKinsey & Company. Available at: https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/the-promise-of-travel-in-the-age-of-ai
24 Areqi, M. A., A. T. Zahary and M. N. Ali (2023). State-of-the-art device-to-device communication solutions. IEEE Access, 11, 46734-46764.
25 Rubio-Andrada, L., M. S. Celemín-Pedroche, M. D. Escat-Cortés and A. Jiménez-Crisóstomo (2023). Passengers' satisfaction with the technologies used in smart airports: An empirical study from a gender perspective. Journal of Air Transport Management, 107, 102347.
26 Ericsson (2024). 5G private networks enable effective mission-critical communications now, while setting the stage for future optimizations across the airport. Available at: www.ericsson.com/en/blog/2024/6/smart-airports-connected-by-cellular-technology.
27 McKinsey (2020). Cybersecurity in a Digital Era. McKinsey & Company. Available at: www.mckinsey.com/~/media/mckinsey/business%20functions/risk/our%20insights/cybersecurity%20in%20a%20digital%20era/cybersecurity%20in%20a%20digital%20era.pdf.

Advanced Human-Machine Interface technologies are making interactions more intuitive, secure and responsive, thereby improving operational efficiency and user experience.

- **Extended reality (XR) technologies**, including virtual reality (VR), augmented reality (AR), and mixed reality (MR), are significantly enhancing Human-Machine Interfaces (HMIs) by providing immersive and interactive experiences.[28] These technologies are particularly beneficial in aviation for training, maintenance, and navigation, offering real-time data overlays and interactive simulations to improve operational efficiency and decision-making.
- **Speech recognition technology** is transforming HMIs by enabling hands-free control and communication with aircraft systems. Such technology allows for more natural and efficient interactions by interpreting and responding to verbal commands.[29] Within the aviation sector, advanced speech recognition systems enhance user experience and safety, enabling pilots and crew to control navigation, communication and other systems through voice commands.
- **Facial recognition technology** enhances security and personalization by identifying and verifying individuals based on their facial features. This technology is used in airports for passenger authentication, ensuring that only authorized individuals can access certain areas, and for monitoring passenger flows, thereby improving security and operational efficiency.[30]
- **Touch displays and data gloves** represent significant advancements in tactile HMIs. Touch displays are widely used in aircraft cockpits and passenger systems, providing intuitive and direct interaction with digital interfaces.[31]
- **HUD (Head-Up Displays)** is revolutionizing the way pilots interact with critical flight information.[32] Such displays project essential data, such as speed, altitude and navigation cues, directly onto the windshield, allowing pilots to keep their eyes fixed on the horizon while accessing necessary information. This technology enhances situational awareness and safety by reducing the need for pilots to look down at instrumentations, thus enabling quicker decision-making and response times. HUDs are increasingly being integrated into modern aircraft to improve operational efficiency and pilot performance.[33]

To further understand the technological advancements driving such innovations, the next chapter will dive into the patent data for these technologies, highlighting key developments and trends in the field. This analysis will provide insights into those proprietary innovations shaping the future of air transportation.

28 Klotz, A. and K. Stendal, (2023). How can Extended Reality (XR) enhance Aviation Personnel Training: A Literature Review. NIKT, 2.
29 Badrinath, S. and H. Balakrishnan, (2022). Automatic speech recognition for air traffic control communications. Transportation Research Record, 2676(1), 798–810.
30 Zhu, T. and L. Wang (2020, March). Feasibility study of a new security verification process based on face recognition technology at airport. In Journal of Physics: Conference Series, 1510(1), 012025. IOP Publishing.
31 Wang, X., W. Guo, Z. Zhong, R. Zeng, J. Zhang and L. Wang (2024). The research of touch screen usability in civil aircraft cockpit. Plos one, 19(2), e0292849.
32 Morfitt, G. E. (2022). Augmenting heads-up displays with intelligent agents: A human factors approach. Master's thesis, Rowan University.
33 Rebensky, S., M. Carroll, W. Bennett and X. Hu (2022). Impact of heads-up displays on small unmanned aircraft system operator situation awareness and performance: A simulated study. International Journal of Human–Computer Interaction, 38(5), 419–431.

Global patent trends

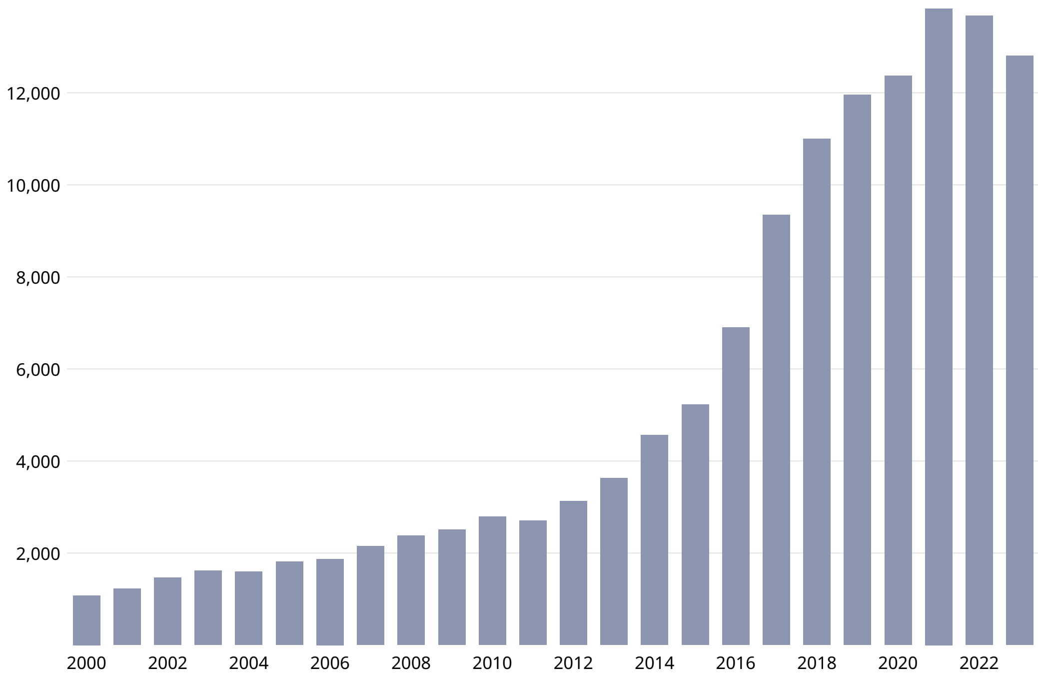
Global patent development

Over the past 20 years, air transport has benefited from many technological advances that have improved efficiency, safety and the passenger experience. These developments can also be seen in the increase in patent activity. Since the beginning of the millennium, the number of patent family publications per year has increased from less than 1,100 in 2000 to more than 12,800 in 2023(Figure C2). This equals a compound annual growth rate of around 11%. In total, the patent search identified more than 123,000 patent families in the field of air transport since 2000. Around 91,400 of these were considered active at the time of this analysis.

However, it is noteworthy that patent family publications reached a preliminary peak in 2021 and have been declining since then. The challenges faced by the aviation industry in recent years, in particular due to the effects of the COVID-19 pandemic, are likely to have contributed to this recent slowdown in patent activity. The pandemic caused a temporary massive decline in air travel and severe disruptions in complex global supply chains, resulting in shortages of key components such as semiconductors. This is most likely to have probably delayed the development and deployment of new technologies in recent years, as the consequent financial losses suffered by companies in the aviation ecosystem led to a shift in focus and resources toward surviving rather than innovating.

Since the beginning of the millennium, it shows an compound annual growth of patent family publications of around 11%

Figure C2 Development of global patent family publications, 2000–2023



Note: Patent family publications per earliest publication year.
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

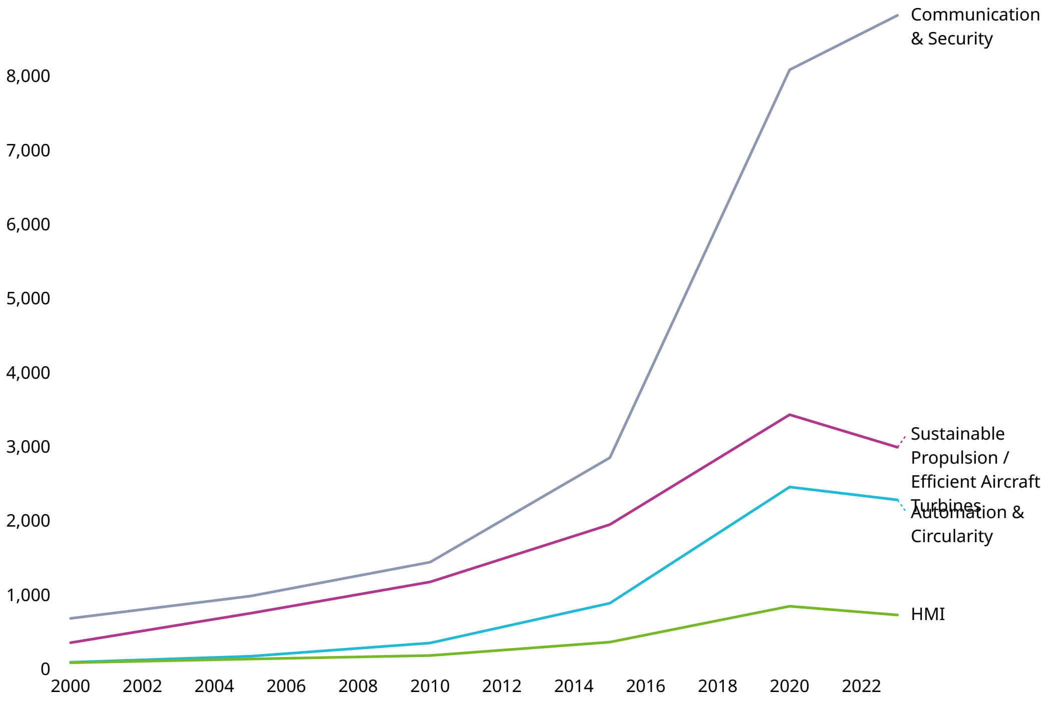
Overview of the four technology trends

To provide an overview of key technology trends, we analyzed and collected all patent family publications related to both to air transport technologies (such as aircraft, helicopters, drones, VTOL, etc.) and each of the four key technology trends (Human-Machine Interaction, Automation and Circularity, Sustainable Propulsion/Efficient Aircraft Turbines, Communication and Security).

Most aviation research activities are focused Communications and Security technology. Between 2000 and 2023, the number of published patent families rose from around 700 to more than 8,800. Sustainable Propulsion/Efficient Aircraft Turbines is another key research area. In this field, the number of patent families published annually has increased from around 350 to almost 3000 since 2000. Automation and recycling technologies have also become an important research area in the aviation industry, as evidenced by the increase in patent publications from only 81 in 2000 to almost 2,300 in 2023. In contrast, Human-Machine Interface technologies still play a minor role in maritime transport, with only about 700 patent family publications in 2023.

Most aviation research activities are focused on communications and security technology

Figure C3 Development of patent family publications in the four technology trends, 2000–2023



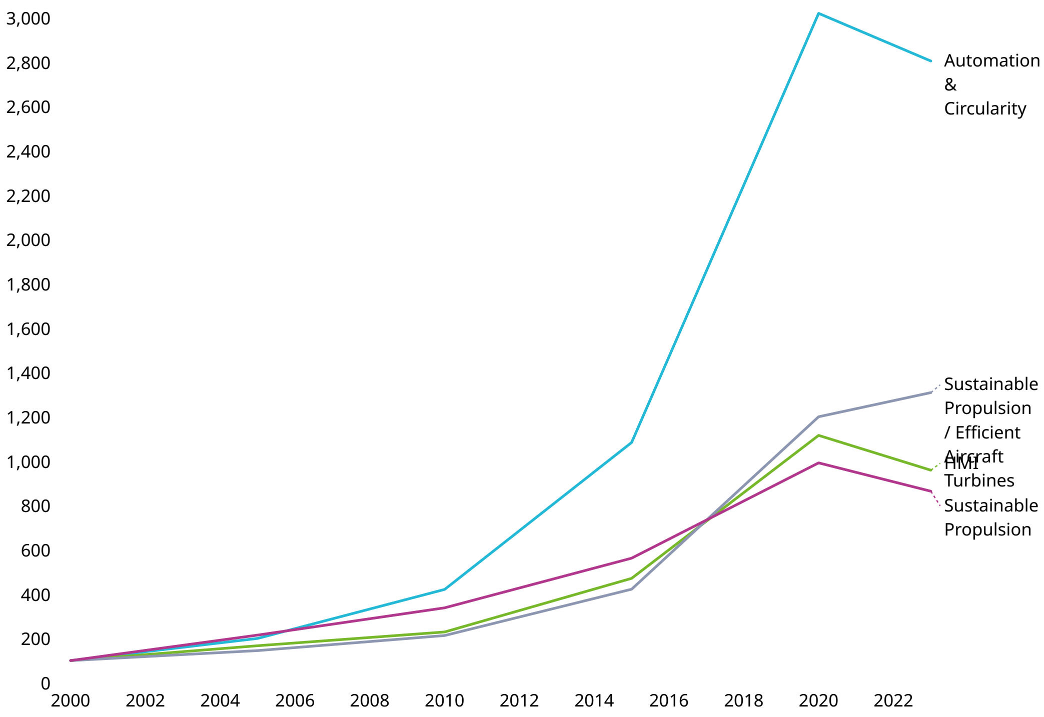
Note: Some patent families are classified in more than one technology trend, therefore the sum of the four technology trends is larger than the total amount of patent family publications.

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Patent growth has been highest in Automation and Circularity technologies, as shown in Figure C4 below, with an average annual annual growth rate of 16% between 2000 and 2023. Patent growth in the other technology trends has averaged around 10% per year. However, patent growth in all four technology trends has been negative in the last two years.

Patent growth in Automation and Circularity technologies has been the highest, with an compound annual growth rate of 16% between 2000 and 2023

Figure C4 Indexed development of patent family publications in the four technology trends, 2000–2023



Note: Indexed development of patent family publications with patent family publications in 2000 = 100.
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Patent coverage

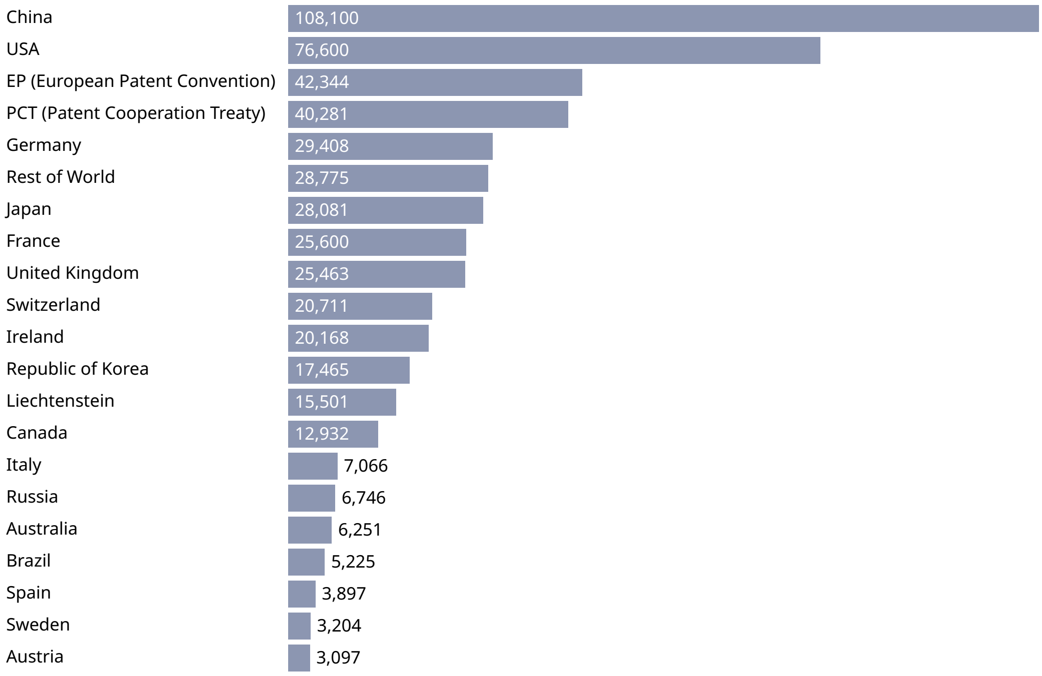
A look at the filing authorities of patent families in air transport technologies allows insights to be gained into global filing strategies.[1] Figure C5 below shows that China is the top country in terms of patent filings. Between 2000 and 2023, more than 108,000 patent families in air transport technologies were filed in China seeking patent protection. The United States of America (US) has also attracted many patent filings since 2000 (76,600).

The third and fourth most important filing authorities are the EP and the PCT. Since 2000, there have been more than 42,000 patent filings under the European Patent Convention and more than 40,000 patent filings under the Patent Cooperation Treaty.

1 Members of patent families can be filed directly in one or more countries, via national patent offices, via the Patent Cooperation Treaty (PCT) route administered by WIPO or via the European Patent Convention (EP) route administered by the European Patent Office.

China and USA collectively account for more than 30% of the global total of patent families

Figure C5 Total patent publications, by filing authority, 2000–2023



Source: WIPO, based on patent data from EconSight/PatentSIght, October 2024.

Top inventor locations

Regional breakdown

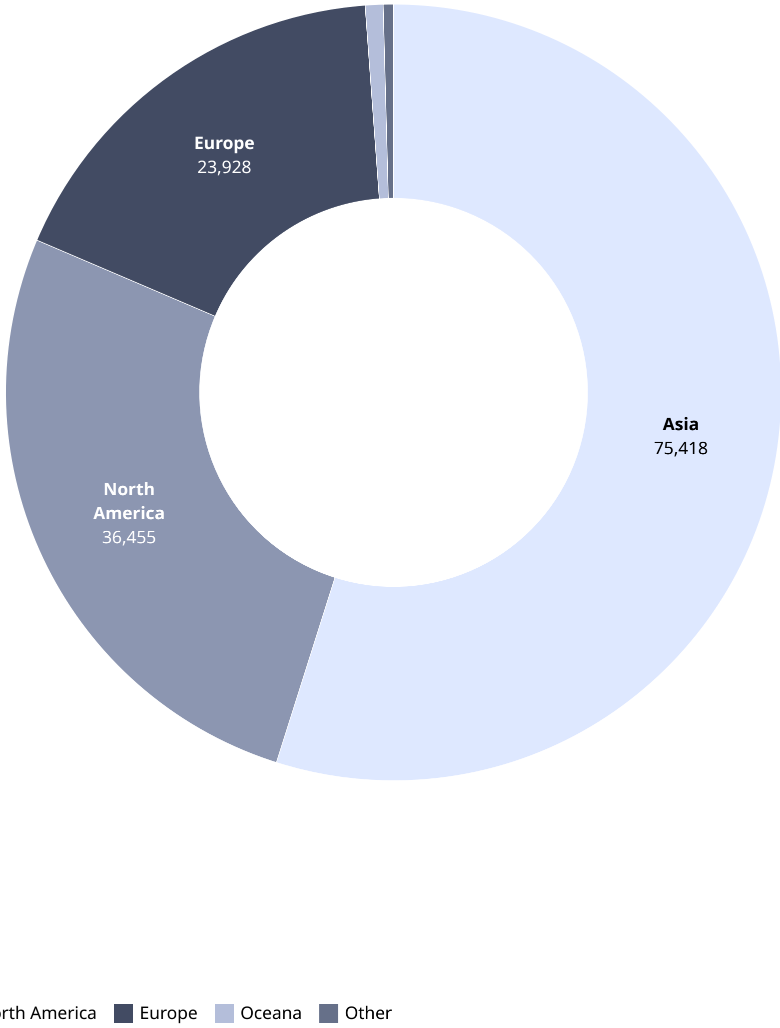
Asia is the most important research region for aeronautical technologies. Between 2000 and 2023, there were more than 75,000 patent families published by inventors based in Asia (Figure C6). This represents more than 57% of all patent families identified. Of course, Northern America (36,455) and Europe (23,928) are also important research regions, thanks to their leading aeronautics companies and research institutes.

The number of patent families from other regions (Africa, Latin America and the Caribbean(LAC) and Oceania) remains rather low.

Note: Some patent families are assigned to more than one region according to the addresses of the inventors, which is why the sum of the shares is greater than 100%.

Asia represents more than 57% of all patent families identified

Figure C6 Regional breakdown: total patent family publications, 2000–2023



Note: Some patent families are assigned to more than one region according to the addresses of the inventors, which is why the sum of the shares is greater than 100%.

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Top inventor countries

At the level of individual countries, China and the United States lead the world in research activity in air transport technologies. Between 2000 and 2023, inventors from China published more than 52,000 patent families in these technologies, while inventors from the United States were responsible for the publication of more than 35,000 patent families (Figure C7). Consequently, these two countries together published almost two thirds of all patent families worldwide.

China's emergence as an aeronautics research powerhouse has been underpinned by political support, with the Government of China making aeronautics a national priority and integrating it into past and current Five Year plans, a series of social and economic development initiatives.[1] Aeronautics is also a key segment of the "Made in China 2025" initiative, which aims to transform China into a high-tech manufacturing powerhouse.[2] As a result, substantial government investment has been made in aerospace research and development, infrastructure and education, including funding for research institutes, laboratories and university programs focused on aerospace engineering.

1 KRWG (2012). China's new plan: A great leap into the air. KRWG Public Media. Available at: www.krwg.org/2012-05-17/chinas-new-plan-a-great-leap-into-the-air.

2 ISDP (2018). Made in China 2025. Institute for Security and Development Policy. Available at: www.isdp.eu/publication/made-china-2025.

One flagship project has been the development of a Chinese commercial aircraft to reduce dependence on foreign aircraft. [3] COMAC (Commercial Aircraft Corporation of China) was established in 2008 for this purpose. The COMAC ARJ21 Xiangfeng, a small regional jet, was put into commercial service in 2016. COMAC has also developed the C919, a narrow-body jet designed to compete with the Boeing 737 and Airbus A320, which currently uses an engine from CFM (joint venture from GE and Safran). The first production airframe was delivered to China Eastern Airlines in 2022 and was put into commercial passenger service in 2023. [4] Moreover, COMAC and Chinese defence contractor Avic are stakeholders in the Aero Engine Corporation of China (AECC) which is developing the CJ-1000 high-bypass turbofan. This engine is supposed to replace the imported CFM Leap engine currently powering the C919. [5]

For many years, the United States has been the dominant force in aeronautics and aviation. A combination of historical, technological, economic and strategic factors has led to this leadership. The origins of the US aviation industry date back to the beginning of the 20th century, marked by the first controlled powered flight by the Wright brothers in 1903 – a pivotal moment in the history of aviation. The two world wars in the first half of the 20th century spurred rapid advances in aviation technology, with the United States at the forefront of innovations such as fighter jets and bombers.

Today, the United States remains a global leader in aviation thanks to its mature and diverse ecosystem, which includes engine manufacturers (such as GE), aircraft manufacturers (such as Boeing) and military aerospace leaders (such as Lockheed Martin, Northrop Grumman and RTX). This ecosystem benefits from institutions such as MIT, Stanford, Caltech, NASA and the National Institute of Aerospace, all of which have leading aerospace engineering programs that contribute to ongoing research and innovation.

Japan is the third most important research location with around 10,500 patent families published between 2000 and 2023. Japan has a strong presence in aeronautics and air transport research with companies such as Mitsubishi Heavy Industries (MHI) and Kawasaki Heavy Industries (KHI), which are suppliers of components and subassemblies to Boeing and Airbus. KHI also makes small patrol and transport aircraft and helicopters. Japan is a leader in materials science, particularly in the development of the lightweight composite materials used in modern aircraft. However, Japan's aerospace industry has suffered setbacks in recent years, with MHI abandoning the development of its Mitsubishi SpaceJet passenger aircraft project following technical setbacks and spiralling costs, and also abandoning its plan to enter the commercial jetliner business.

France (8,754 published patent families) and Germany (7,542) are the leading European research locations. Together, these two countries are major forces in aeronautics research, particularly through their collaboration in Airbus, a world leader in the manufacture of commercial aircraft. In addition to Airbus, other key French and German research players include companies such as MTU Aero Engines, Safran and Thales, institutions such as the German Aerospace Center (DLR) and the French Aerospace Research Agency (ONERA) and major universities (e.g. the Technical University of Munich and the École Polytechnique).

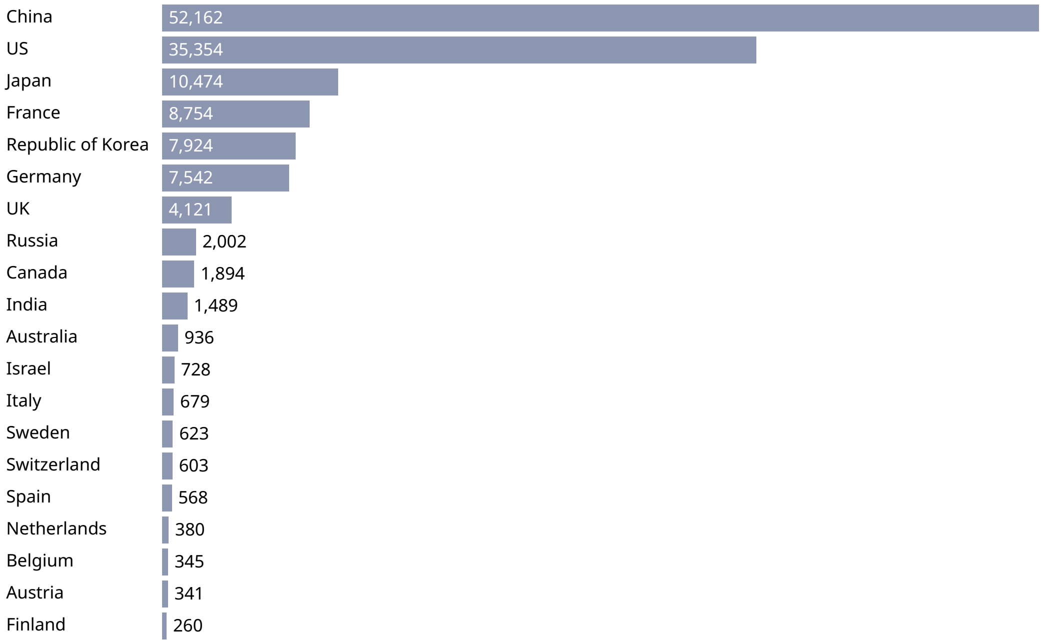
Other important countries for aeronautics research are the Republic of Korea (7,924) and the United Kingdom (UK) (4,121). The Russian Federation, Canada and India rank 8th to 10th, with over 1,000 patent family publications each since 2000.

Australia, Israel and several European countries (Italy, Sweden, Switzerland, Spain, the Kingdom of Netherlands, Belgium, Austria and Finland) complete the rest of the top 20 inventor locations. These top 20 inventor locations account for the majority of patenting activity related to air transport technologies.

3 ANN (2024). Long way to go for China’s first homegrown airliner. Asia News Network. Available at: https://asianews.network/long-way-to-go-for-chinas-first-homegrown-airliner.
4 CNN (2024). China’s homegrown passenger jet makes international debut. Available at: https://edition.cnn.com/2024/02/19/business/china-comac-c919-international-debut-intl-hnk/index.html.
5 South China Morning Post (2024). How monumental is China’s challenge to build its own jet engine for the C919 as it seeks aviation self-reliance? Available at: www.scmp.com/economy/china-economy/article/3251482/how-monumental-chinas-challenge-build-its-own-jet-engine-c919-it-seeks-aviation-self-reliance.

China and USA published almost two thirds of all patent families worldwide

Figure C7 Top inventor locations: total patent family publications, 2000–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Development and patent growth since 2000

Figure C8 shows that China has become the leading research location in air transport, as well as in the other transport modes. From just 10 patents in 2000, the number of patents from China has skyrocketed to around 8,100 in 2023. Along the way, China overtook the United States in terms of annual patent publications in 2016 and has held top spot ever since.

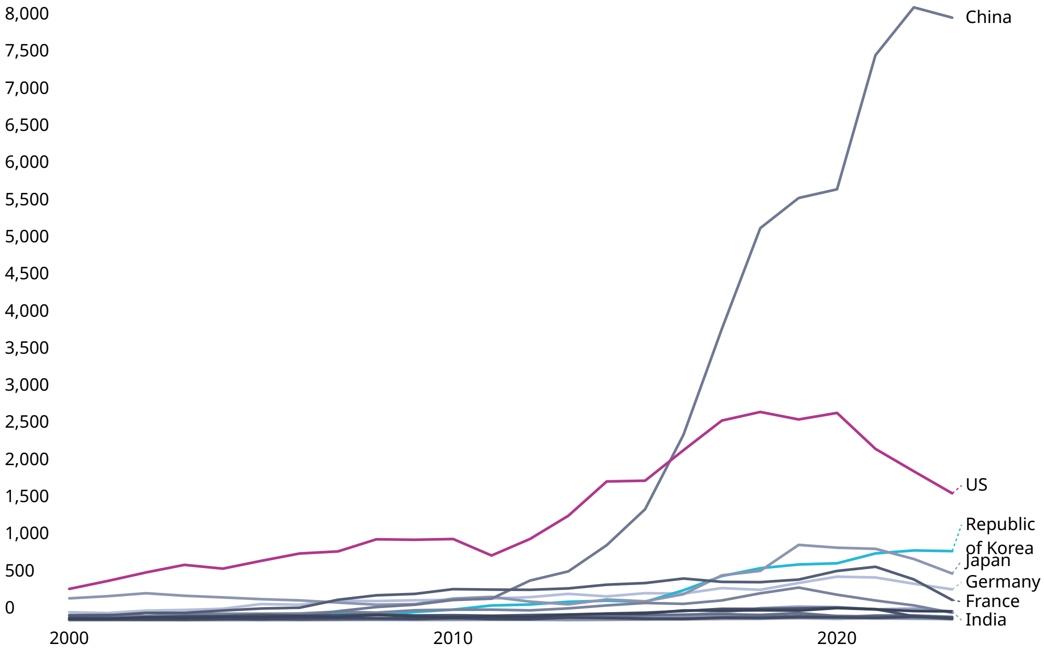
Patent family publications have recently decreased in most major countries owing to the postCOVID-19 pandemic challenges mentioned above, and the United States is no exception. US patent family publications increased relatively steadily between 2000 and 2018 (from 422 to 2,805) but have since decreased significantly (to 1,709 in 2023). An additional factor likely to have contributed to this are the current problems at Boeing, which have led to a decline in innovation activity at the US aircraft manufacturer.

The Republic of Korea has continued to increase its patent family publications in recent years. As a result, with more than 900 patent family publications in 2023, the Republic of Korea ranks third in the country ranking. The country has made significant strides in aviation and has experienced rapid growth, particularly in passenger and freight traffic. Key players include universities such as the Korea Advanced Institute of Science and Technology (KAIST) as well as companies such as Korea Aerospace Industries (aircraft manufacturer), which is developing the KAI KF-21 fighter jet together with US Lockheed Martin,[6] and Hanwha Aerospace, which develops and manufactures engines, avionics and other critical components for both military and commercial aircraft.

6 The Korea Times (2024). KAI signs $1.41 billion deal to start full-scale production of KF-21 fighter jet. Available at: www.koreatimes.co.kr/www/nation/2024/06/113_377387.html.

China surpassed the US in annual patent publications in 2016 and has maintained the lead ever since

Figure C8 Top 10 inventor locations: development of patent family publications, 2000–2023



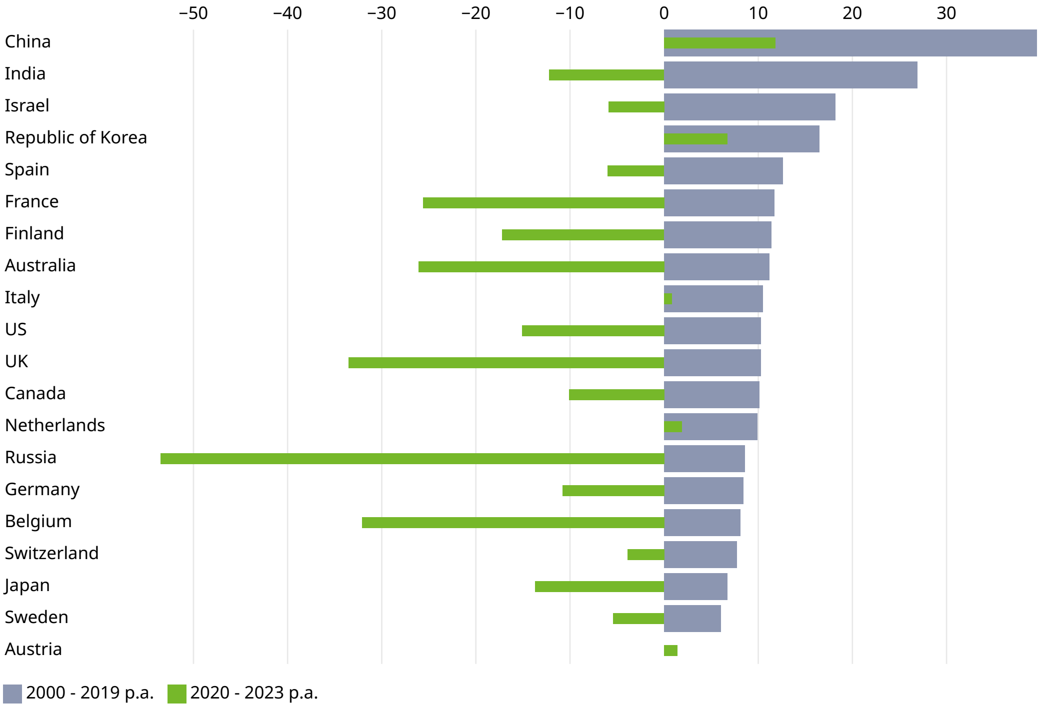
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

In terms of growth rates of patent families, China,India, Israel and the Republic of Korea are ahead with very dynamic growth rates between 2000 and 2019. China and the Republic of Korea alsocontinued to have high positive growth rates for the period from 2020 to 2023.

The most dynamic European country is Spain with a very high compound annual growth between 2000 and 2019 (12.6% p.a.) (Figure C9). However, patenting activity from Spain has declined since 2020. A similar picture emerges for Israel.

China, India, Israel and the Republic of Korea led with dynamic growth rates between 2000 and 2019

Figure C9 Top inventor locations: growth of patent family publications, 2000–2019 and 2020–2023



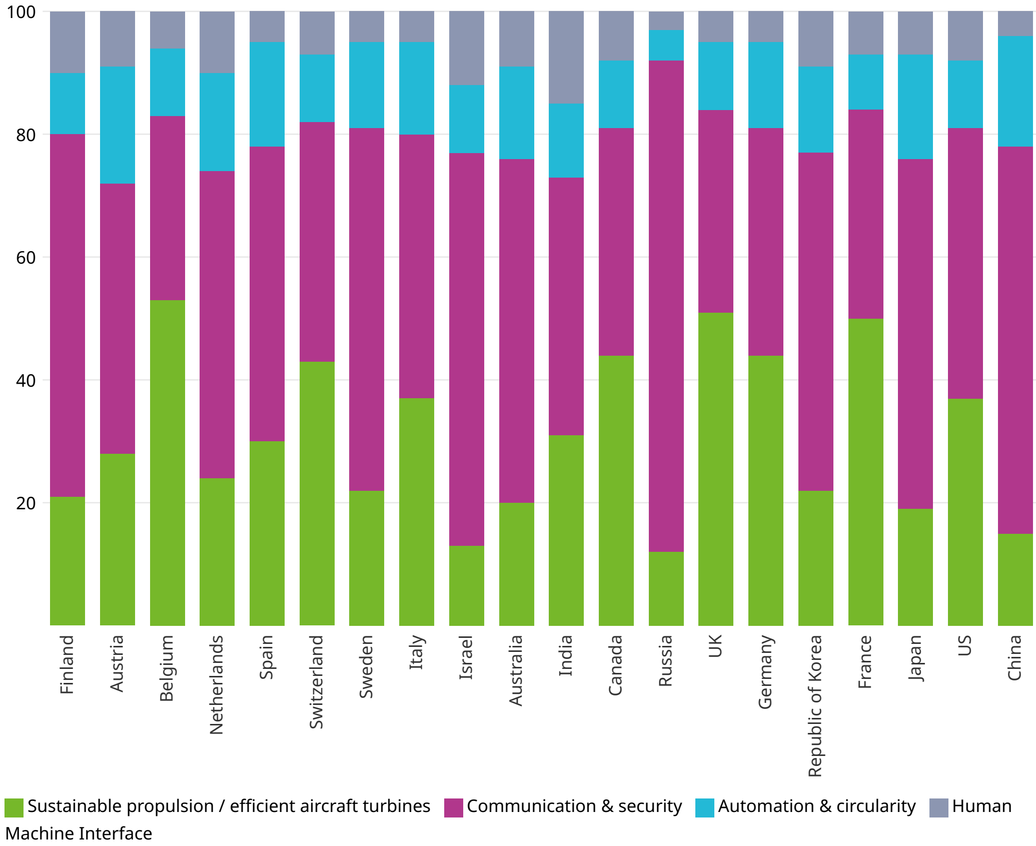
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Research priorities: countries

A closer look at the research priorities at a country level reveals significant differences. Communication and Security technologies are clearly the dominant research focus areas for the leading Asian research locations (China, Japan and Republic of Korea) (Figure C10 and Table C1). By contrast, the area of Sustainable Propulsion/efficient aircraft turbines is the main research topic of the top European countries (France, Germany and the United Kingdom). In the United States, research efforts are more evenly distributed between Communication and Security and Sustainable Propulsion/efficient aircraft turbines.

Communication and Security technologies dominate research in leading Asian locations: China, Japan and the Republic of Korea

Figure C10 Top 20 countries: research priorities, by share



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Sustainable Propulsion, particularly efficient aircraft turbines, is the primary research focus in Europe's top countries: France, Germany and the UK

Table C1 Top countries: research priorities, by volume

		Air transport total	Sustainable propulsion	Automation & circularity	Communication & security	Human Machine Interface
1	China	52,162	9,235	11,151	39,421	2,330
2	US	35,354	15,151	4,658	17,769	3,450
3	Japan	10,474	2,540	2,256	7,545	964
4	France	8,754	4,722	900	3,197	618
5	Republic of Korea	7,924	2,148	1,316	5,359	894
6	Germany	7,542	3,740	1,165	3,101	429
7	UK	4,121	2,353	489	1,518	259
8	Russia	2,002	265	98	1,675	63
9	Canada	1,894	956	229	791	183
10	India	1,489	536	215	720	260
11	Australia	936	230	180	649	110
12	Israel	728	119	96	574	110
13	Italy	679	285	117	330	39
14	Sweden	623	161	101	422	34
15	Switzerland	603	309	78	278	54
16	Spain	568	195	108	307	30
17	Netherlands	380	107	73	220	45
18	Belgium	345	206	43	114	25
19	Austria	341	120	79	189	38
20	Finland	260	63	32	178	31

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Top inventor locations per technology trend

The differences in research priorities mentioned above are also reflected in the country rankings for the four transport technology trends. While China is the clear leader in both Communication and Security and Automation and Circularity technologies, US inventors have published the most patent families in Sustainable Propulsion/Efficient Aircraft Turbines and HMI technologies (Figure C11).

Other notable facts are the important role of France and Germany in Sustainable Propulsion/ efficient aircraft turbines, the strong research position of Japan in Automation and Circularity and the relative strength of the Republic of Korea in HMI technologies.

China leads in Communication & Security and Automation & Circularity technologies, while the US dominates in Sustainable Propulsion and HMI patents

Figure C11 Total patent family publications, 2000–2023

	Sustainable Propulsion Summe 2000 - 2023	Automation&Circularity Summe 2000 - 2023	Communication&Security Summe 2000 - 2023	HMI Summe 2000 - 2023
US	15,151	4,658	17,769	3,450
China	9,235	11,151	39,421	2,330
France	4,722	900	3,197	618
Germany	3,740	1,165	3,101	429
Japan	2,540	2,256	7,545	964
UK	2,353	489	1,518	259
Republic of Korea	2,148	1,316	5,359	894
Canada	956	229	791	183
India	536	215	720	260
Switzerland	309	78	278	54
Italy	285	117	330	39
Russia	265	98	1,675	63
Australia	230	180	649	110
Belgium	206	43	114	25
Spain	195	108	307	30
Sweden	161	101	422	34
Austria	120	79	189	38
Israel	119	96	574	110
Netherlands	107	73	220	45
Finland	63	32	178	31

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Relative Specialization Index

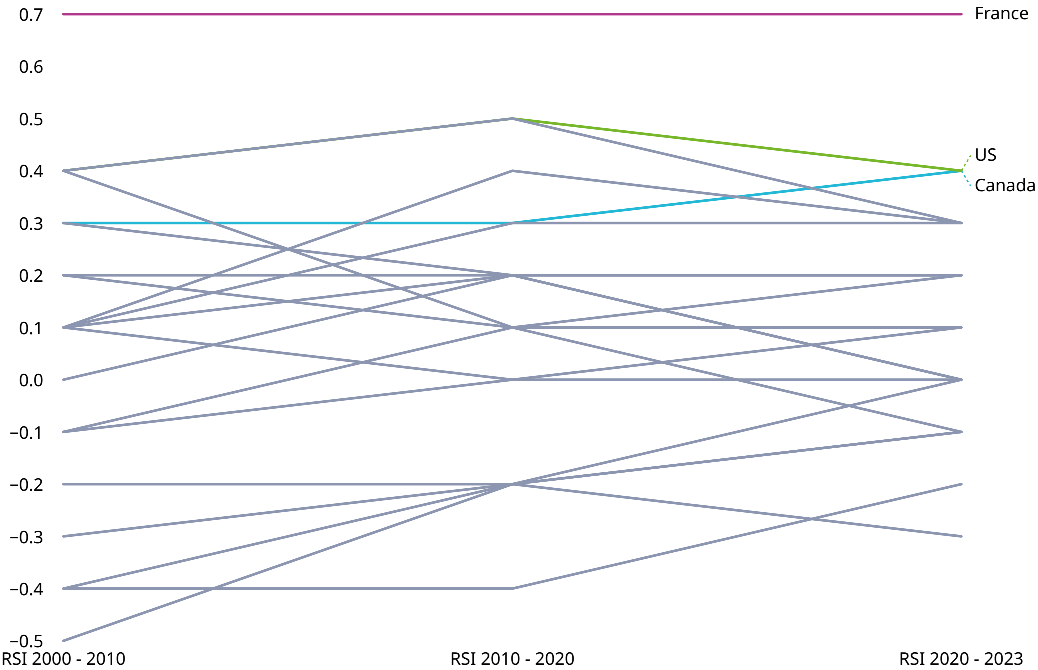
The Relative Specialization Index (RSI) is a metric used to compare a country's (or company's) patenting activity in a specific research field against its overall patenting activity. It shows how much a country specializes in a particular area compared to its overall research profile. A positive RSI indicates that a country is specializing in a particular field more than the global average, whereas a negative RSI suggests a country is specializing less in a particular field compared to the global average.

The RSI for air transport technologies illustrates the extraordinarily important role of aviation in France (Figure C12). France reaches a very high RSI index of 0.7 over every observed time periods which is much higher than the second placed the United States (RSI of 0.4 in most recent years). Air transport research is also very important in Canada, India and the United Kingdom, even though the RSI in India and the United Kingdom has declined somewhat in recent years.

At the opposite end of the country ranking of the top 20 nations in air transport research are the N Kingdom of the Netherlands and Japan, whose negative RSI scores indicate a low level of specialization.

The RSI for air transport technologies highlights the critical importance of aviation in France

Figure C12 Top 20 countries: relative specialization, 2000–2023



Note: RSI is relative specialization index.

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

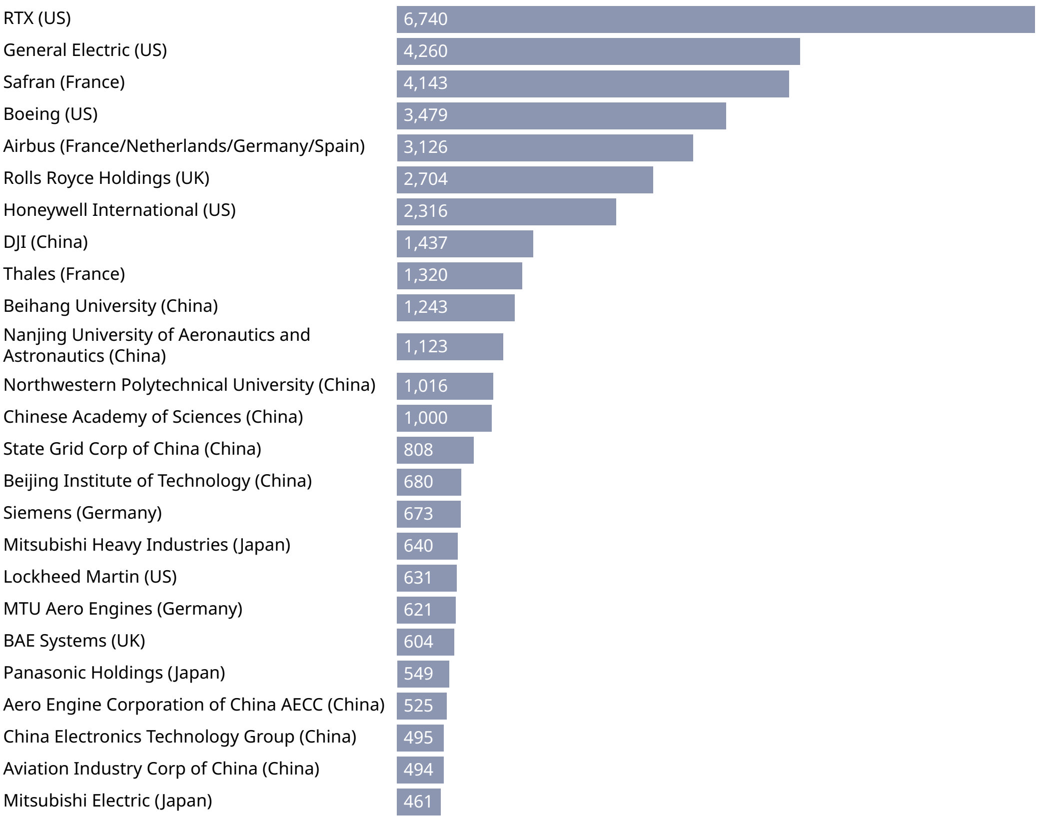
Top patent owners

Top patent owners: patent activity

The list of the world's top research companies highlights the important role of US companies in aeronautics research. Three of the top five patent owners are US companies - RTX (1st), General Electric (2nd) and Boeing (4th), with the remaining two places going to French Safran (3rd) and European Airbus (5th) (Figure C13).

The world's top research companies underscore the key role of US firms in aeronautics innovation

Figure C13 Top patent owners, 2000–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

RTX Corporation, formerly Raytheon Technologies Corporation, is a major aerospace and defence company. RTX's research activities focus on advances in engine efficiency and alternative propulsion for aircraft, next-generation avionics and innovations in materials science to create lighter and stronger aircraft structures.

General Electric (GE Aerospace) is a US aircraft engine manufacturer. GE's joint venture with French engine manufacturer Safran (ranked third in the top contenders) – CFM International – is the world's largest commercial aircraft engine manufacturer.

Boeing and Airbus are both leading commercial aircraft manufacturers and major defence contractors. The two companies have formed a global duopoly for commercial aircraft since the 1990s.

Drone manufacturer DJI is the top Chinese patent owner in the field of aeronautical technology. There are also many Chinese research institutions with sizeable patent portfolios in air transport technologies such as the Beihang University, the Nanjing University of Aeronautics and Astronautics, the Northwestern Polytechnical University and the Chinese Academy of Sciences.

Top patent owners: patent growth

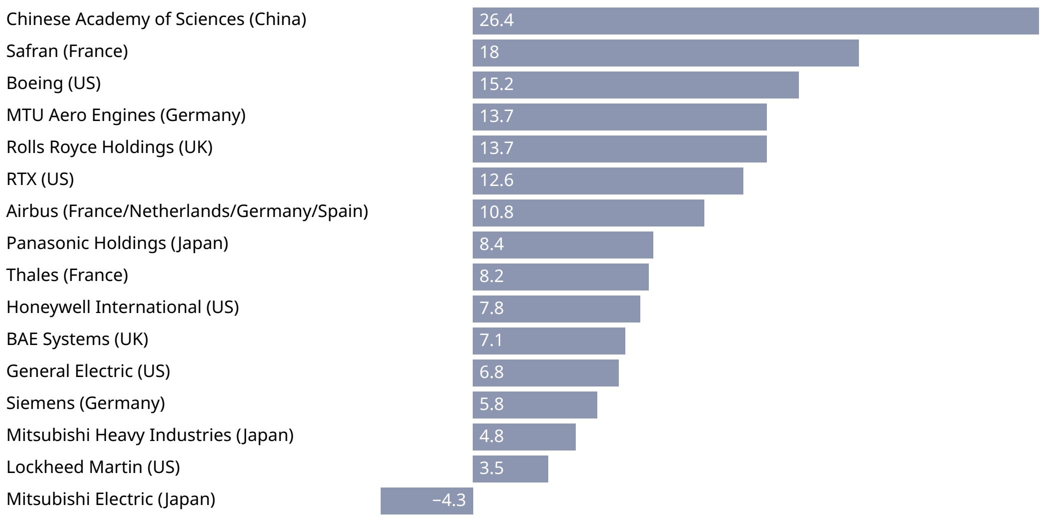
Patenting activity in air transport technologies has grown dynamically over the last decades (Figures C14–C18). Almost all top patent owners have increased their patent portfolios over the entire period analysed from 2000 to 2023 (Figure C14). However, since 2020, many of the top patent owners have been on a downward trend in their annual patent family publications (Figure C15). As mentioned above, research activities have temporarily slowed down owing due to the challenges faced by the aeronautics industry in recent years, in particular due to the effects of the COVID-19 pandemic.

The only exception is China, where most of the top applicants like the Aero Engine Corporation of China, the Beijing Institute of Technology and the Northwestern Polytechnical University have further expanded their patent portfolios dynamically (Figure C15).

Mitsubishi Heavy Industries is the only non-Chinese company among the top 25 patent applicants to have increased its aviation patent family publications since 2020.

Mitsubishi Electric is the only top company with a shrinking portfolio size

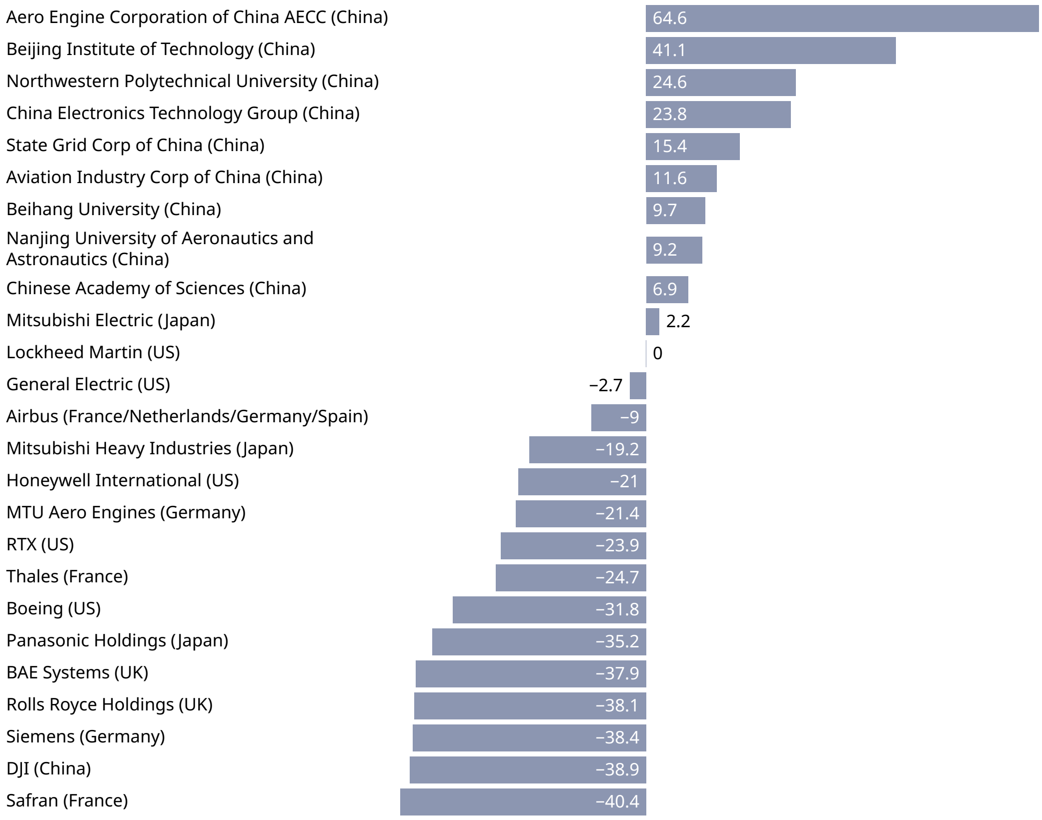
Figure C14 Top patent owners, growth 2000–2019 (p.a.)



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Since 2020, many of the top patent owners have been on a downward trend in their annual patent family publications

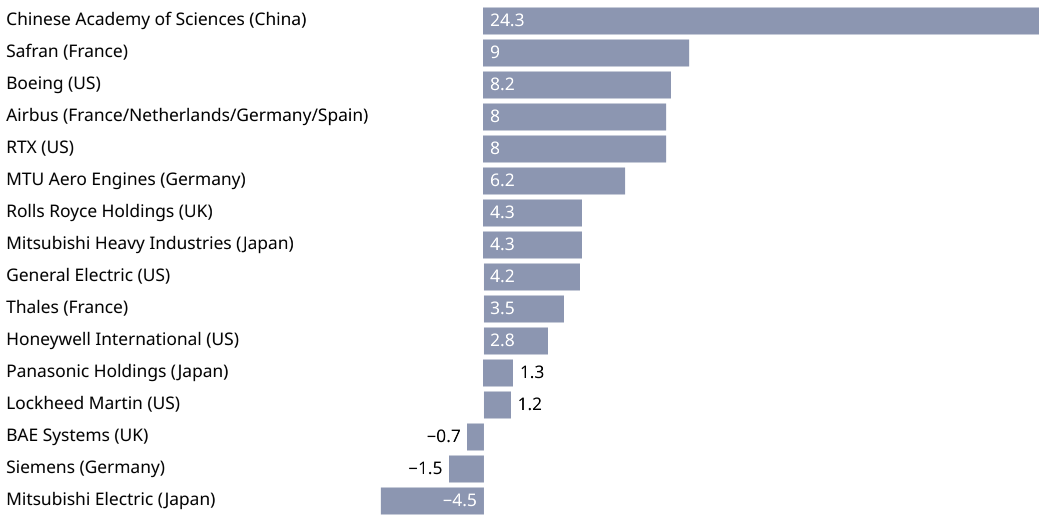
Figure C15 Top patent owners, growth 2020–2023 (p.a.)



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Most top patent owners expanded their portfolios between 2000 and 2023

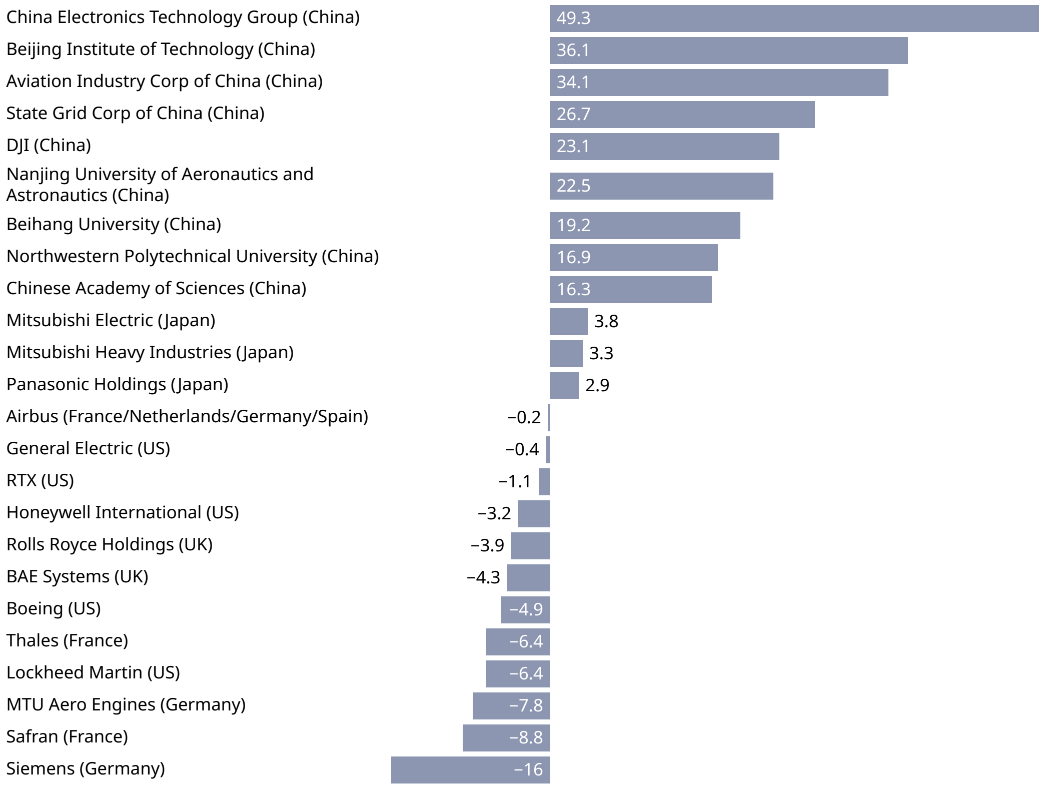
Figure C16 Top patent owners, growth 2000–2023 (p.a.)



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Since 2013, all top patent owners with the highest growth have been from Asia, predominantly China

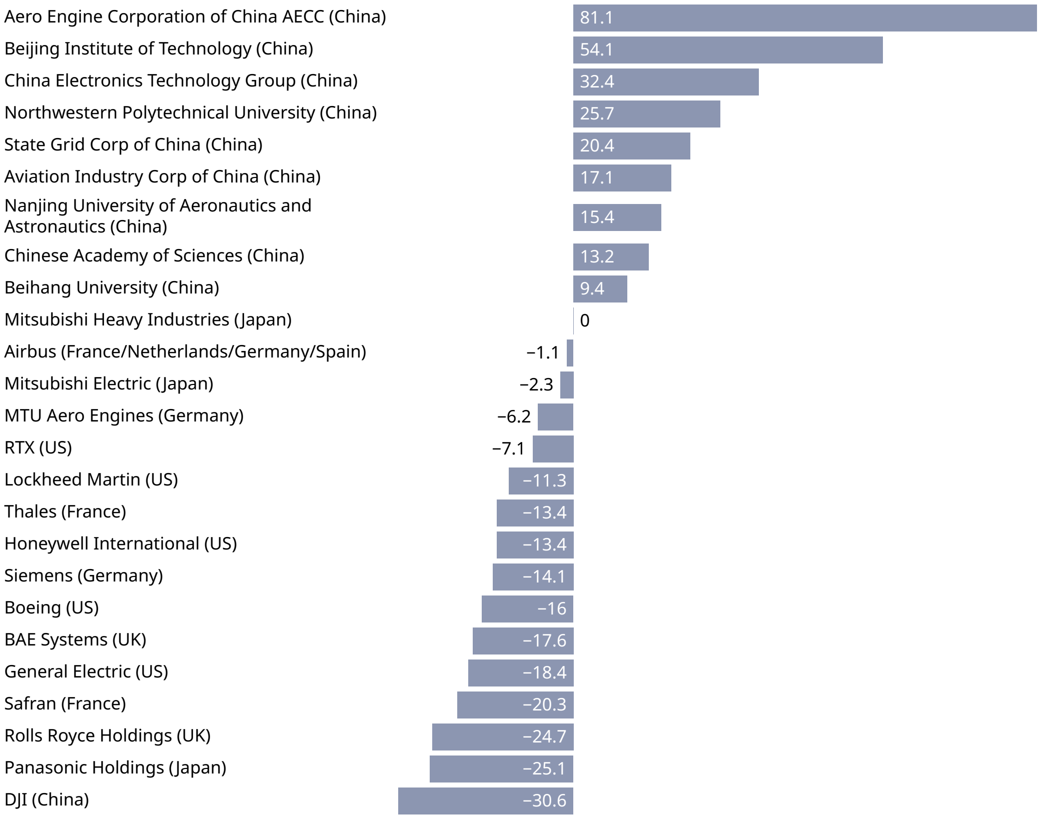
Figure C17 Top patent owners, growth 2013–2023 (p.a.)



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Since 2018, all top patent owners with the highest growth are from China

Figure C18 Top patent owners, growth 2018–2023 (p.a.)



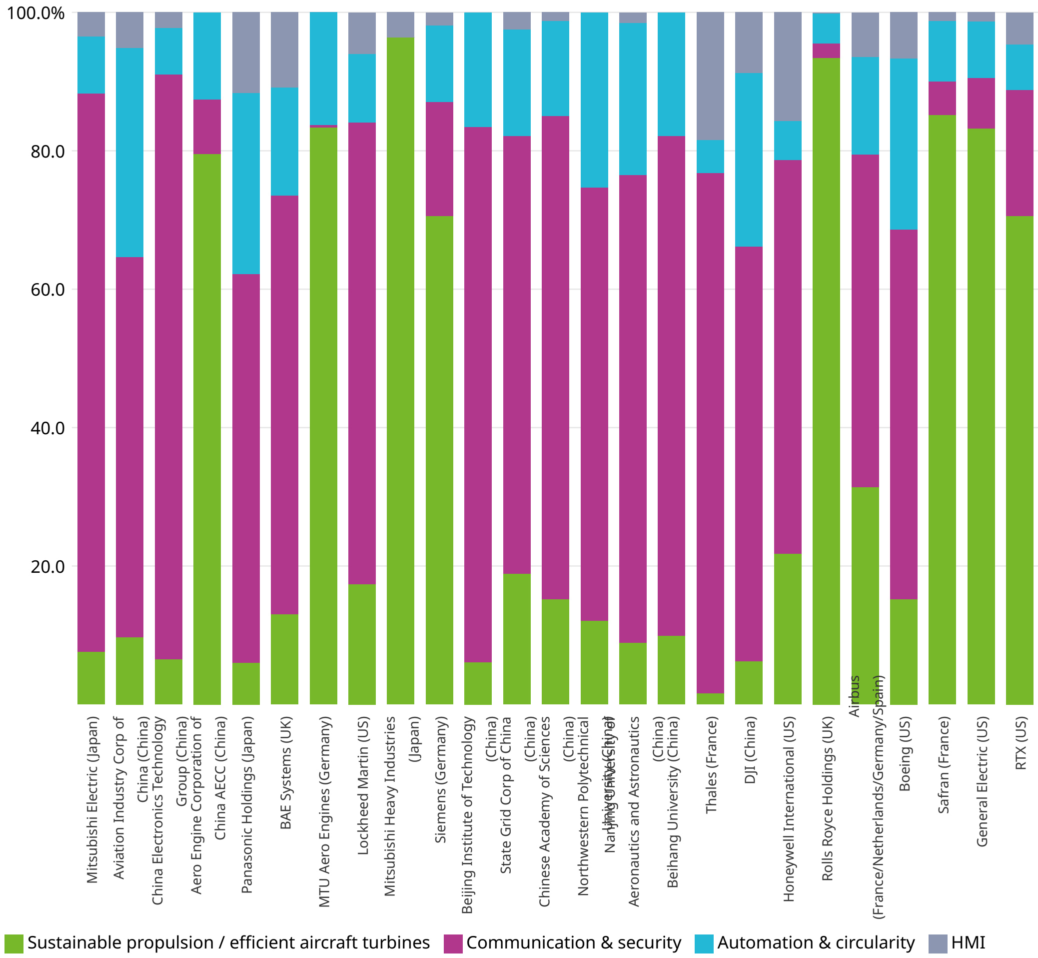
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Top patent owners: research priorities

The research priorities of the top applicants show, unsurprisingly, that engine manufacturers such as RTX, GE, Safran, Rolls-Royce, MTU Aero Engines and Aero Engine Corporation of China clearly focus on the development of Sustainable Propulsion/efficient aircraft engine technologies (Figure C19). RTX has the largest total patent portfolio in this technology trend.

Top applicants, including engine manufacturers like RTX, GE, Safran, Rolls-Royce, MTU Aero Engines, and Aero Engine Corporation of China, primarily focus on Sustainable Propulsion and efficient aircraft engine technologies

Figure C19 Top 25 patent owners: research priorities



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Most of the other top research companies instead publish patent families mainly in the Communication and Security technology sector. Examples include Thales, Mitsubishi Electric, China Electronics Technology Group, Beihang University and Honeywell. However, Boeing is the leader in Communication and Security technologies in absolute patent numbers (Figure C20).

Some companies also show a strong research focus on Automation and Circularity technologies, including Boeing, DJI, Toyota, Panasonic and Aviation Industry of China (AVIC). Again, Boeing has the largest patent portfolio in this field.

HMI technologies play an important role in the research activities of Honeywell and Thales.

Most top companies focus on Communication and Security, led by Boeing, Airbus and DJI in patents

Figure C20 Top 25 patent owners: patent family publications, 2000–2023

	Sustainable propulsion / efficient aircraft turbines	Communication & security	Automation & circularity	HMI
RTX (US)	4,974	1,283	467	325
General Electric (US)	3,783	330	371	60
Safran (France)	3,671	209	377	53
Rolls Royce Holdings (UK)	2,606	59	121	4
Airbus (France/Netherlands/Germany/Spain)	1,059	1,621	476	216
Boeing (US)	615	2,165	1,000	270
Honeywell International (US)	557	1,453	144	401
MTU Aero Engines (Germany)	553	2	108	0
Siemens (Germany)	528	123	83	14
Aero Engine Corporation of China AECC (China)	431	43	68	0
Mitsubishi Heavy Industries (Japan)	293	0	0	11
State Grid Corp of China (China)	184	615	150	24
Chinese Academy of Sciences (China)	173	794	156	14
Northwestern Polytechnical University (China)	136	706	285	0
Beihang University (China)	136	993	245	0
DJI (China)	134	1,279	536	187
Lockheed Martin (US)	122	469	70	42
Nanjing University of Aeronautics and Astronautics (China)	113	855	279	19
BAE Systems (UK)	86	401	103	72
Aviation Industry Corp of China (China)	51	289	159	27
Panasonic Holdings (Japan)	50	467	217	97
Beijing Institute of Technology (China)	46	585	125	0
Mitsubishi Electric (Japan)	39	415	42	18
China Electronics Technology Group (China)	35	452	36	12
Thales (France)	24	1,103	70	271

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Patenting activity in the four technology trends

Sustainable Propulsion/Efficient Aircraft Turbines

The Sustainable Propulsion/Efficient Aircraft Turbines technology trend consists of five subcategories: batteries, efficient aircraft turbines, electric propulsion, hydrogen/fuel cells and sustainable carbon-based fuels.

The most important area in terms of patent family publications is efficient aircraft turbines. The number of patent family publications in this area has increased from 286 in 2000 to 1,200 in 2023 after peaking at 2,115 in 2020 (Figure C21). More efficient aircraft turbines are a key area of research into improving the sustainability of aviation. Important recent developments include the further development of high bypass ratio turbofans, which improve fuel efficiency and reduce emissions. A major advantage of research into more efficient aircraft turbines is that they can make a more rapid contribution to reducing emissions than other more transformative types of Sustainable Propulsion technology, such as electric aircraft, as they can be more easily retrofitted to existing commercial aircraft.

The second most important research area is batteries, where patent family numbers have grown from 34 to 1,322 between 2000 and 2023. Patent family publications in electric propulsion have also risen significantly over the years. Electric planes promise zero emissions, making them ideal for short regional flights and urban air mobility. However, significant progress, especially in battery technology, is essential to enable larger electric aircraft types to fly for more than a very short distances. The main drawback of the current generation of batteries is their weight and low energy density compared to kerosene and hydrogen. [1] As a result, while smaller electric aircraft are expected to enter the market for short-haul flights within the next 5-10 years, more technological breakthroughs are needed for larger planes and long-haul applications. However, hybrid-electric concepts could be a viable option for longer routes with larger aircraft in the medium term. [2]

Patent family publications related to the use of hydrogen/fuel cells in aviation have also steadily increased over the last years. Hydrogen aircraft offer a longer-term solution with higher energy density and zero emissions, but also face significant hurdles in terms of infrastructure development and storage complexity. While hydrogen aircraft could be commercially viable for regional and short-haul flights by 2035, widespread adoption for long-haul flights depends on overcoming these challenges and building a global hydrogen infrastructure.

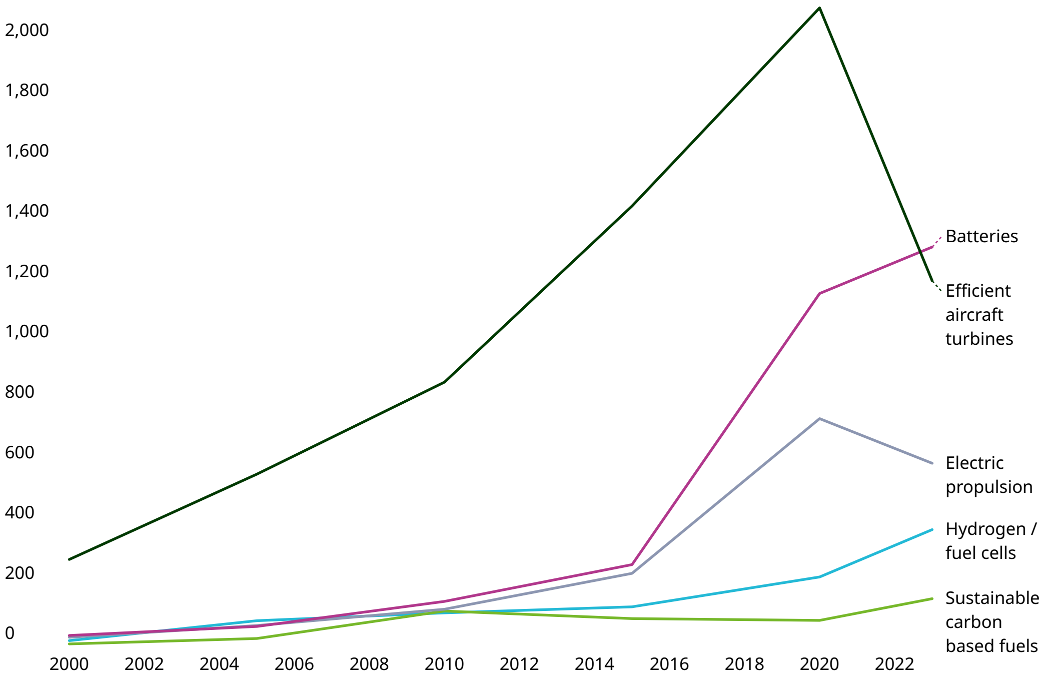
Another challenge for companies is that new more sustainable technologies such as hydrogen- or battery-powered aircraft, must be able to meet the high and complex safety standards in aviation, as safety is so crucial within the sector. Certification is also a challenge considering that for example regulations applicable to electric aircraft are still in the making in most regions. [3]

1 Airbus (2023). Electrifying the sky: How hybridisation plays a role in aviation's future. Available at: www.airbus.com/en/newsroom/stories/2023-03-electrifying-the-sky.
2 DW (2023). Are electric planes ready for takeoff? Available at: www.dw.com/en/are-electric-planes-ready-for-takeoff/a-64491147.
3 Politico (2024). Why electric aircraft may never be the next big thing. Available at: www.politico.eu/article/electric-aircraft-emissions-aviation-pipistrel.

Patenting activity in the field of sustainable aviation fuel(SAF) increased at the end of the 2000s peaking in 2010 with 115 patent families. After plateauing at this level for a few years, patenting activity declined and did not pick up significantly until 2023 (156 patent family publications). SAF offers a more immediate solution to reducing greenhouse gas emissions than electric or hydrogen-powered aircraft, as the use of SAFs is compatible with existing aircraft and infrastructure. However, SAF is currently more expensive than conventional jet fuel and limited by feedstock availability and production capacity.

Batteries and efficient aircraft turbine patents show opposing trends after 2020

Figure C21 Sustainable Propulsion/efficient aircraft dynamics: development of global patent family publications, 2000–2023

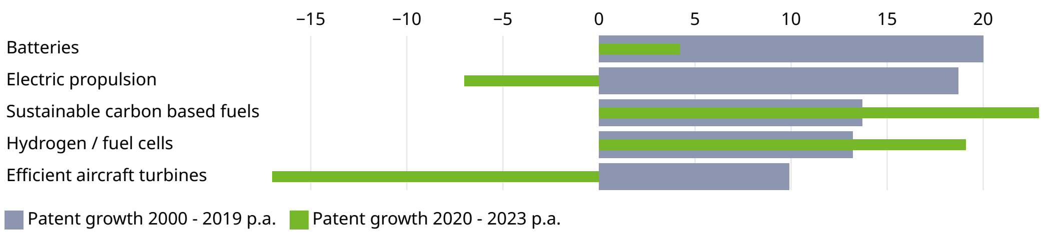


Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Looking at the compound annual growth rates over different time periods, innovation activity was dynamic in all subcategories between 2000 and 2019, but growth rates have been mixed from 2020 onward (Figures C22–C24). While the number of patent families in hydrogen/fuel cells and sustainable fuels continues to grow dynamically, patenting activity in efficient aircraft turbines and electric propulsion has decreased significantly (Figure C22).

While the number of patent families published in speech recognition continues to grow, the number of patent families published annually in head-up displays has stagnated

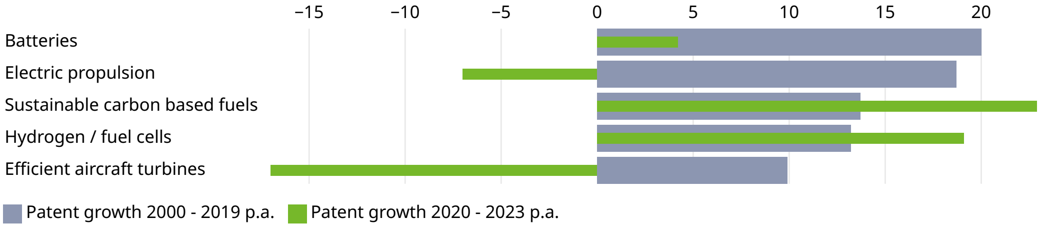
Figure C22 Sustainable Propulsion/efficient aircraft dynamics: growth of patent family publications, 2000–2019 and 2010–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Batteries are the only area accelerating more in the last 10 years than over 20 years

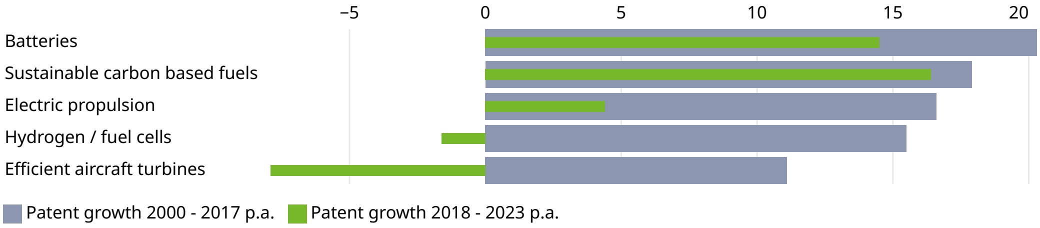
Figure C23 Sustainable Propulsion/efficient aircraft dynamics: growth of patent family publications, 2000–2023 and 2013–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

From 2000 to 2017, all subcategories saw dynamic innovation, but growth has varied since 2018

Figure C24 Sustainable Propulsion/efficient aircraft dynamics: growth of patent family publications, 2000–2017 and 2018–2023

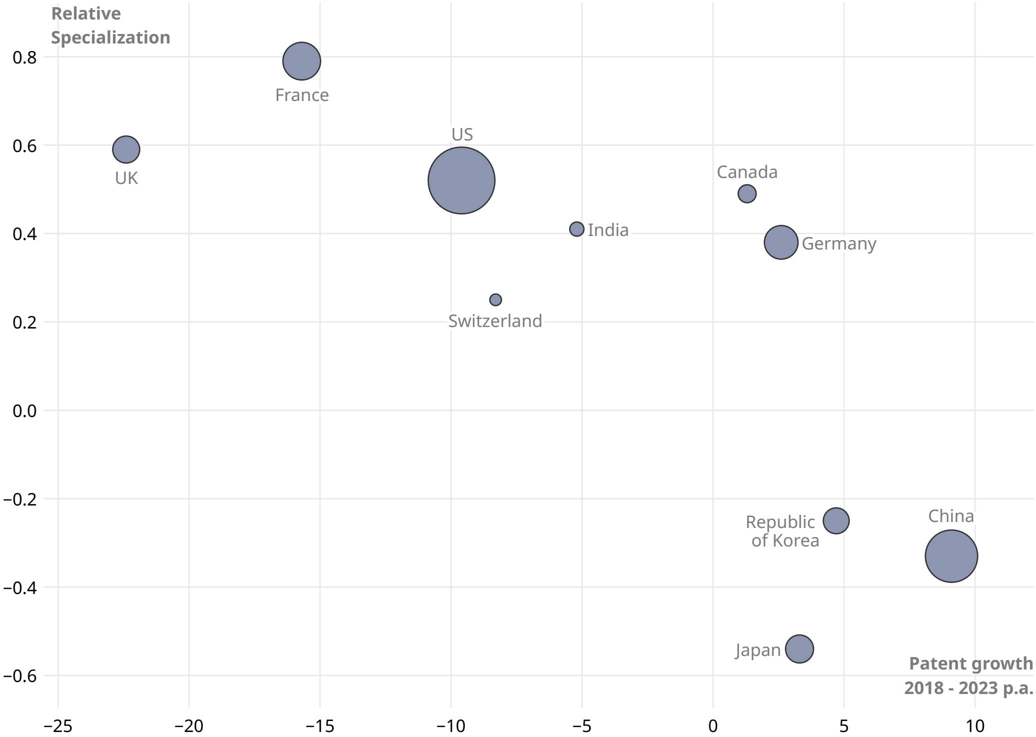


Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Figure C25 shows that US inventors are still responsible for most patent family publications, but China is catching up owing to having much higher growth rate. In addition, RSI values show that France and the United Kingdom have the highest degree of specialization in Sustainable Propulsion/Efficient Aircraft Turbines, mainly due to the research activities of Safran and Airbus in France and Rolls-Royce in the United Kingdom.

US inventors lead in patent publications, but China is rapidly catching up with higher growth rates

Figure C25 Sustainable Propulsion/Efficient Aircraft Turbines: country comparison, RSI (2000–2023) and growth rates (2018–2023)



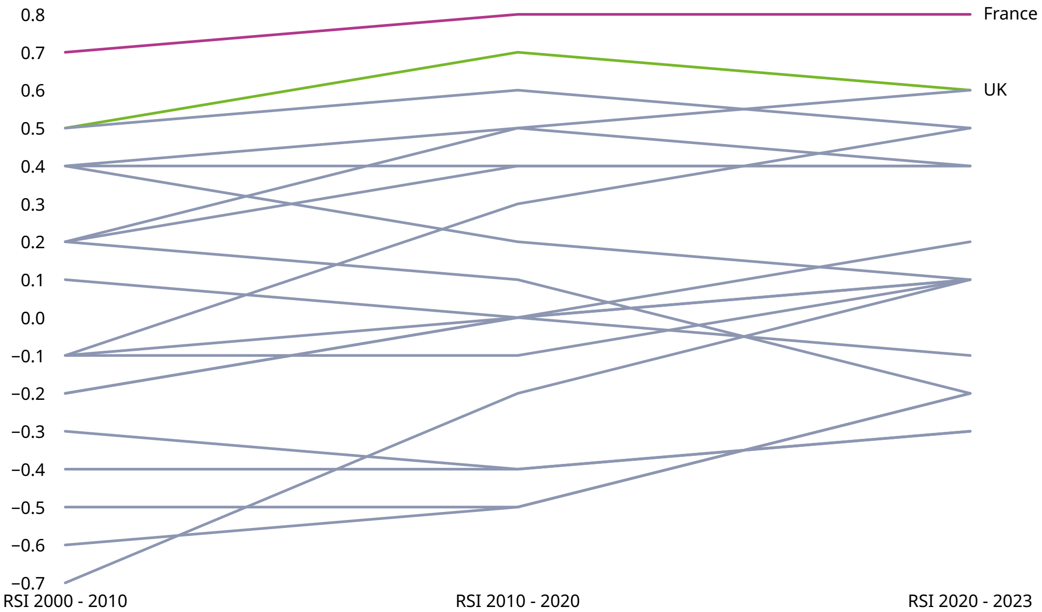
Note: The size of the bubbles shows the number of patent family publications at the country level in the field of Sustainable Propulsion/efficient aircraft. The average annual patent growth rates are for 2018–2023, and the Relative Specialization Index (RSI) for the whole period analyzed, 2000–2023.

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Looking more closely at RSI values over different time periods, the high degree of specialization in France is once again highlighted (Figure C26). Other highly specialised countries are the United Kingdom, Canada, the United States, Spain and Germany. Spain, in particular, has significantly increased its RSI in Sustainable Propulsion/efficient aircraft engines over the years.

RSI values over time again highlight France's high specialization

Figure C26 Sustainable Propulsion/Efficient Aircraft Turbines: top 20 countries' RSI, 2000–2023



Note: RSI is relative specialization index.
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Analysis of the top research countries in the different subgroups of Sustainable Propulsion/efficient aircraft turbines provides the following key results (Figure C27):

- The United States is the technology leader in efficient aircraft turbines with more than 12,000 patent families published between 2000 and 2023. France and China follow at a considerable distance in second and third place.
- China is leveraging its technological leadership and know-how in battery technologies into aviation. With more than 5,000 patent family publications since 2000, the country is clearly in the lead, ahead of the United States and the Republic of Korea.
- Electric propulsion research in aviation is dominated by China and the United States.
- The United States, Germany and China are the top three research nations for hydrogen/fuel cell research in aviation.
- The United States leads in the research and development of sustainable aviation fuels.

The US leads in Hydrogen/Fuel Cells, Sustainable Fuels, and Efficient Aircraft Turbines

Figure C27 Top 20 inventor locations for Sustainable Propulsion/Efficient Aircraft Turbines subgroups, 2000–2023

	Batteries Patent family publications 2000 - 2023	Electric Propulsion Patent family publications 2000 - 2023	Hydrogen/Fuel Cells Patent family publications 2000 - 2023	Sustainable Fuels Patent family publications 2000 - 2023 in sustainable fuels	Efficient Airturbine Design Patent family publications 2000 - 2023 in Efficient aircraft turbines
China	5,034	2,762	616	368	3,185
US	2,099	1,552	1,061	643	12,024
Republic of Korea	1,035	708	257	64	902
Germany	866	503	647	145	2,310
Japan	822	525	284	125	1,469
France	370	278	243	104	4,071
UK	268	224	229	100	1,899
Canada	129	85	80	93	754
Australia	82	63	44	52	109
Russia	61	30	39	7	159
Switzerland	61	54	29	9	226
Italy	55	48	21	17	187
India	51	32	22	19	455
Israel	48	34	15	7	43
Austria	45	22	25	14	49
Sweden	35	27	11	8	107
Spain	33	22	37	14	120
Netherlands	31	21	22	32	40
Poland	15	6	6	3	89
Belgium	14	11	23	9	168

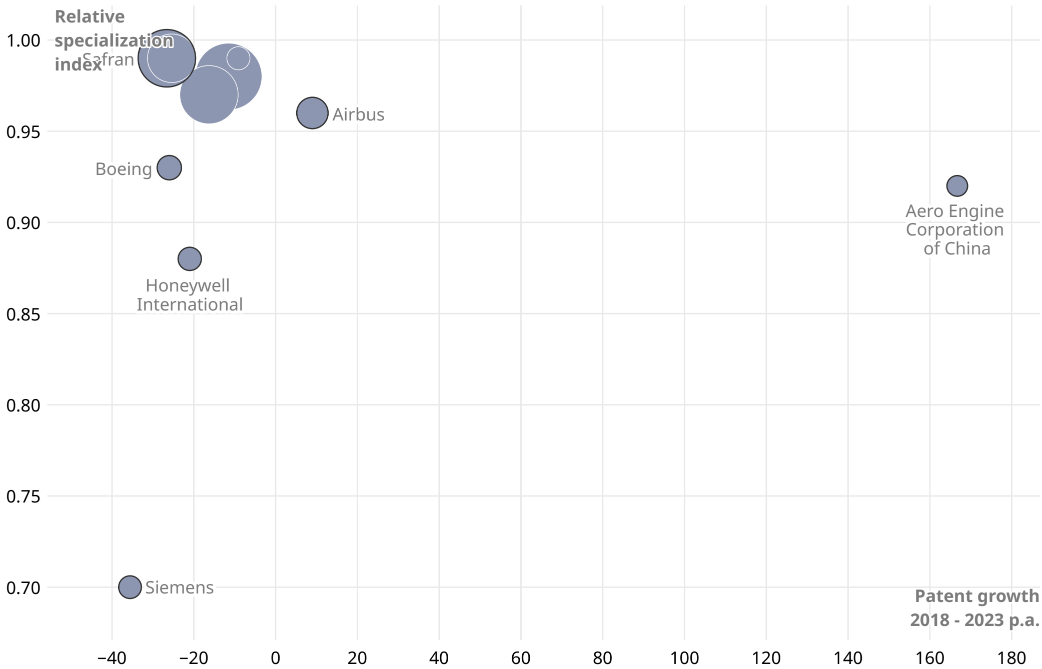
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

RTX, GE, Safran, Rolls-Royce and Airbus are the top research companies in Sustainable Propulsion/Efficient Aircraft Turbines in terms of patent family publications. Being aerospace companies, they all have very high RSI scores (Figure C28).

However, patent family publications have declined since 2018 for most of the top applicants. Only Airbus and Aero Engine Corporation of China (AECC) have grown their patent portfolios since 2018. AECC in particular stands out, with an average patent growth rate of more than 160% per year over the last five years.

Only Airbus and AECC have grown their patent portfolios since 2018, with AECC achieving over 160% annual growth in the past five years

Figure C28 Sustainable Propulsion/Efficient Aircraft Turbines: comparison of top patent owners, RSI (2000–2023) and growth rates (2018–2023)



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Regarding the top patent owners in the five subgroups, the following results can be stated (Figure C29):

- Airbus is a research leader in batteries, electric propulsion, hydrogen and fuel cells and SAFs. An example is the E-Fan X project where Airbus together with Siemens and Rolls Royce developed a hybrid-electric aircraft demonstrator, in which one of the jet engines on a BAe 146 test aircraft was replaced with a 2 MW electric motor.[4] Another example is EcoPulse, a distributed hybrid-propulsion demonstrator aircraft, developed in partnership with Daher and Safran. Airbus is contributing battery technology and aerodynamic modelling to the project.[5] The ZEROe project by Airbus focuses on hydrogen powered aircraft concepts.[6] The goal is to bring a hydrogen-powered plane to market by 2035.
- Boeing and its subsidiary Aurora Flight Sciences are cooperating with GE and NASA on the development of a hybrid electric engine to power a single aisle aircraft.[7] The company and its subsidiary, Wisk, are also developing uncrewed passenger-carrying urban air mobility operations using eVTOLS.[8]
- Shell is a research leader in sustainable fuels. The company is currently building a 820,000-tons-a-year biofuels facility in Rotterdam to produce sustainable aviation fuel (SAF) and renewable diesel made from waste.[9]
- RTX is the leader in research on more efficient aircraft turbines. For example, Pratt and Whitney, a subsidiary of RTX, announced in 2023 it had to have developed a patent-pending new technology for calculating turbine thrust using lasers to enable the high-fidelity measurement of key parameters including velocity, temperature and density.[10]

4 Airbus. E-Fan X: A giant leap towards decarbonising flight. Available at: www.airbus.com/en/innovation/low-carbon-aviation/hybrid-and-electric-flight/e-fan-x.
5 Airbus. EcoPulse: A new approach to distributed propulsion for aircraft. Available at: www.airbus.com/en/innovation/low-carbon-aviation/hybrid-and-electric-flight/ecopulse.
6 Airbus. ZEROe: Towards the world's first hydrogen-powered commercial aircraft. Available at: www.airbus.com/en/innovation/low-carbon-aviation/hydrogen/zeroe.
7 GE Aerospace (2022). Electric skies: Boeing joins GE and NASA's hybrid electric flight project: Available at: www.geaerospace.com/news/articles/sustainability-technology/electric-skies-boeing-joins-ge-and-nasas-hybrid-electric-flight.
8 Boeing Future of Flight. Air taxi by Wisk. Available at: www.boeingfutureofflight.com/wisk.
9 S&P Global (2023). Shell to deliver first SAF from Rotterdam plant from 2025. Available at: www.spglobal.com/commodityinsights/en/market-insights/latest-news/agriculture/050323-shell-to-deliver-first-saf-from-rotterdam-plant-from-2025.
10 PR Newswire (2023). Pratt & Whitney and Virginia Tech pioneer laser-optical thrust and emissions measurement for gas turbines. Available at: www.prnewswire.com/news-releases/pratt--whitney-and-virginia-tech-pioneer-laser-optical-thrust-and-emissions-measurement-for-gas-turbines-301851939.html.

Airbus leads research in batteries, electric propulsion, hydrogen/fuel cells, and SAFs, Shell excels in sustainable fuels, and RTX dominates in efficient aircraft turbine research

Figure C29 Top 5 patent owners in the subgroups of Sustainable Propulsion/Efficient Aircraft Turbines

Subgroup	Company	Country	Patent Family Publications
Batteries	RTX	US	130
Batteries	State Grid Corp of China	China	162
Batteries	Boeing Co	US	162
Batteries	Beta Air LLC	US	169
Batteries	Airbus SE	EU	213
Electric Propulsion	State Grid Corp of China	China	79
Electric Propulsion	Safran SA	France	81
Electric Propulsion	Boeing Co	US	113
Electric Propulsion	RTX Corp	US	115
Electric Propulsion	Airbus SE	EU	118
Hydrogen & Fuel Cells	Boeing Co	US	69
Hydrogen & Fuel Cells	RTX Corp	US	83
Hydrogen & Fuel Cells	Safran SA	France	85
Hydrogen & Fuel Cells	General Electric Co	US	89
Hydrogen & Fuel Cells	Airbus SE	EU	307
Sustainable Fuels	Neste Oyj	Finland	17
Sustainable Fuels	Honeywell International Inc	US	20
Sustainable Fuels	General Electric Co	US	22
Sustainable Fuels	Shell PLC	UK	42
Sustainable Fuels	Airbus SE	EU	45
Efficient Aircraft Turbines	Airbus SE	EU	632
Efficient Aircraft Turbines	Rolls Royce Holdings PLC	UK	2,523
Efficient Aircraft Turbines	Safran SA	France	3,484
Efficient Aircraft Turbines	General Electric Co	US	3,679
Efficient Aircraft Turbines	RTX Corp	US	4,772

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Automation and Circularity

Automation and Circularity technologies in the air transport field include the areas of smart production, efficient material use and recycling.

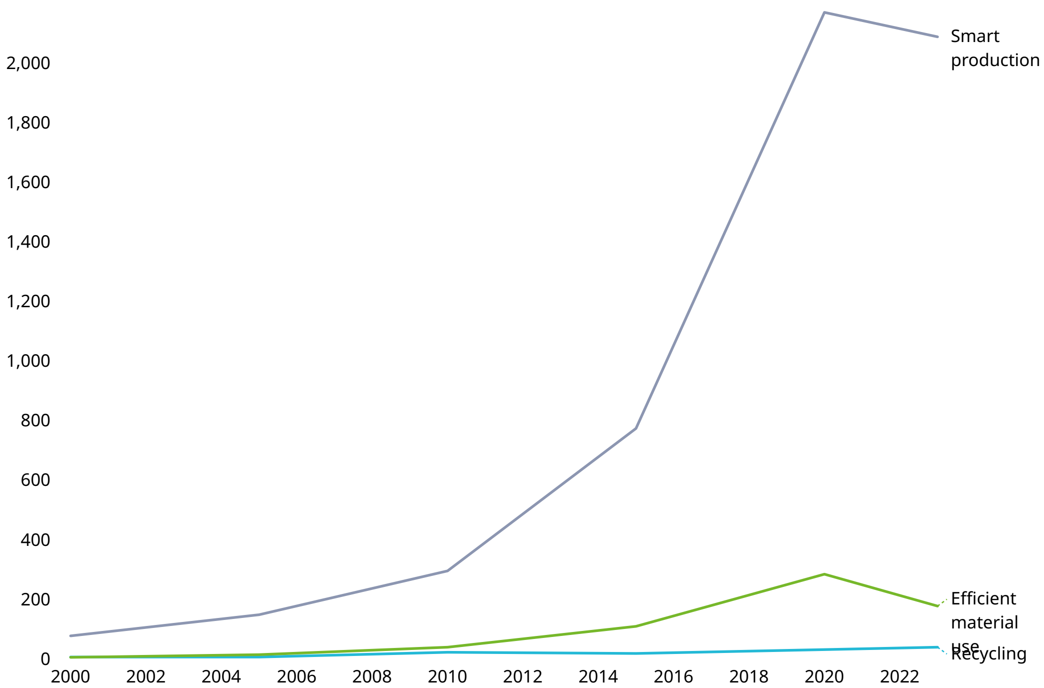
Smart production is the major research area within Automation and Circularity. The number of patent family publications in this technology area has increased from only 75 in 2000 to almost 2,100 in 2023 after having reached an even higher peak of 2,442 in 2021 (Figure C30). Smart production is transforming aviation by incorporating advanced technologies such as automation, AI and IoT into manufacturing processes, so as to increase efficiency, reduce costs and improve product quality.[11] Key research areas include digital twins for simulating and optimizing production, additive manufacturing (3D printing) for creating complex components

11 Aeroreport (2020). Smart factory in aviation: More complicated, but worthwhile. Available at: https://aeroreport.de/en/innovation/smart-factory-in-aviation-more-complicated-but-worthwhile.

and advanced robotics for precise assembly tasks. Furthermore, AI software and tools are increasingly integrated into quality control to better detect manufacturing irregularities or deviations. These innovations enable real-time monitoring and predictive maintenance, streamline production lines and accelerate the development of new aircraft models.

Smart production is the key research area in Automation and Circularity, with patent publications rising from 75 in 2000 to nearly 2,100 in 2023, peaking at 2,442 in 2021

Figure C30 Automation and Circularity: development of global patent family publications, 2000–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Patent family publications in the field of efficient material use have risen from only 3 in 2000 to 175 in 2023. Efficient material use in aviation is crucial for enhancing performance, reducing costs and minimizing environmental impact. Key research developments focus on lightweight composite materials that offer high strength-to-weight ratios, such as carbon fiber-reinforced polymers, leading to improved fuel efficiency and reduced emissions.[12] Additionally, research into additive manufacturing (3D printing) allows for the precise fabrication of lightweight components with minimal waste.[13]

The number of patent family publications related to recycling in air transport remains low. In 2023, only 37 patent families were published. Nonetheless, aircraft recycling is crucial for sustainable aviation, potentially reducing the industry's environmental impact by minimizing waste generation and lowering the overall carbon footprint. Key research and development efforts focus on innovative methods for recycling the composites and metals used in aircraft structures, including advanced processes for reusing carbon fibre composites and efficient methods for recovering and reusing aluminium and titanium. However, recycled materials require extensive testing and certification in order to meet stringent regulatory standards before they can be used again for aircraft production, which can be prohibitively expensive and time-consuming.

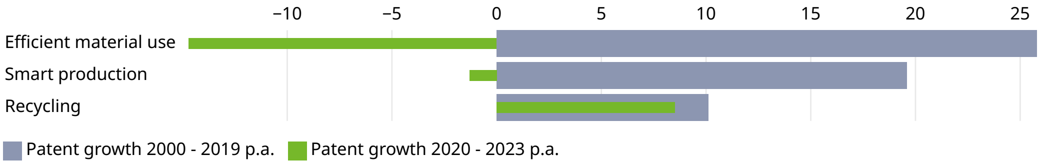
Patent growth in Automation and Circularity technologies was very dynamic in all subgroups between 2000 and 2019 (Figures C31–C33). However, from 2020 onward, patent growth has

12 sensXPERT (2023). The impact of composites in the aviation industry. Available at: www.sensxpert.com/blog/impact-composites-aviation-industry.
13 Linköping University (2018). Materials for more efficient aviation. Available at: https://liu.se/en/news-item/material-for-ett-effektivare-flyg.

been negative in smart production and efficient material use (Figure C31). Only patent family publications in recycling have continued to grow in recent years, albeit from a low level.

Patent growth in Automation and Circularity technologies was highly dynamic across all subgroups from 2000 to 2019

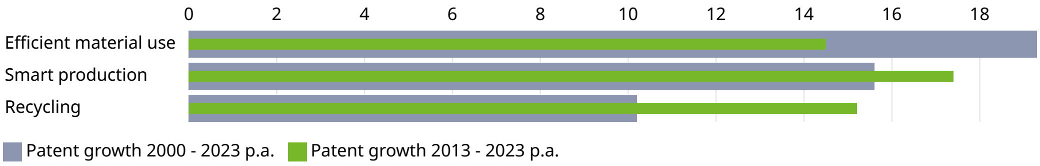
Figure C31 Automation and Circularity: growth of patent family publications, 2000–2019 and 2020–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Since 2020, patent growth has declined in smart production and efficient material use

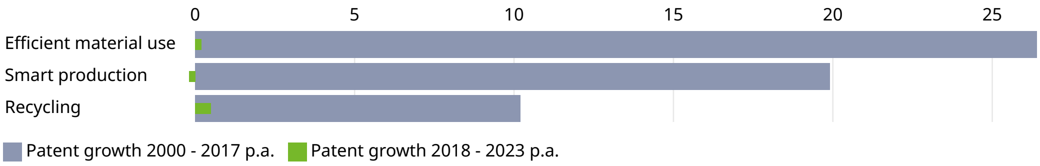
Figure C32 Automation and Circularity: growth of patent family publications, 2000–2023 and 2013–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Patent publications in recycling have continued to grow in recent years, though from a low base

Figure C33 Automation and Circularity: growth of patent family publications, 2000–2017 and 2018–2023



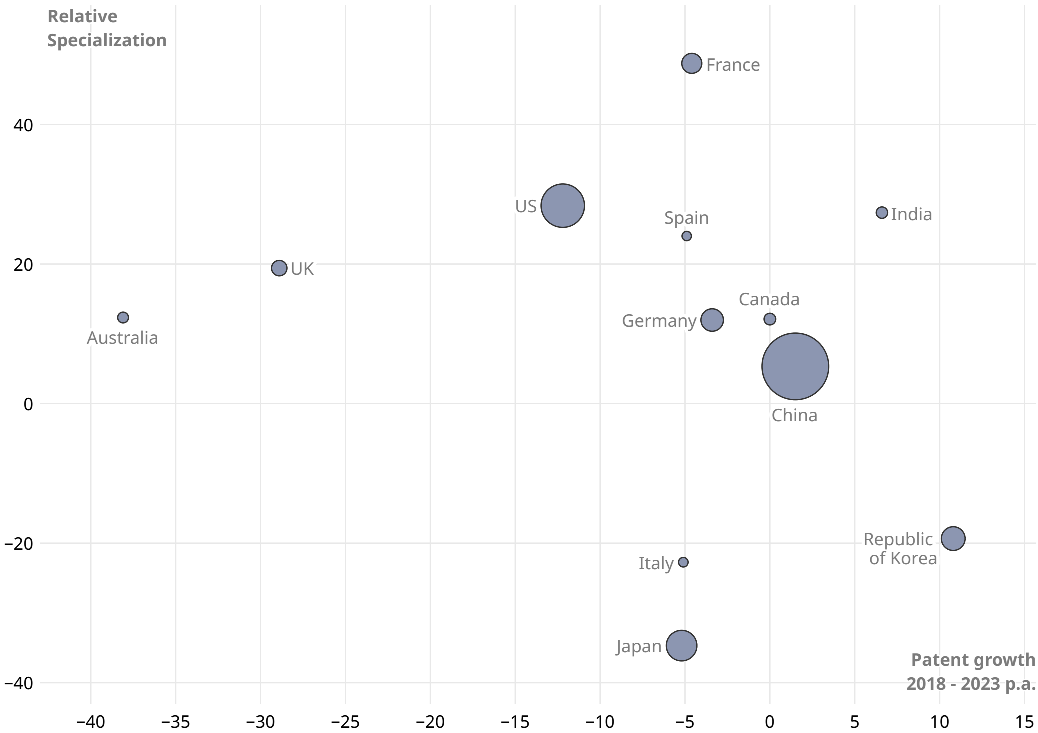
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

A country comparison shows that China is ahead in Automation and Circularity research activities in terms of total patent family publications (Figure C34). However, patent growth has been the highest in the Republic of Korea since 2018. In contrast, patenting activity has declined substantially in Australia and the United Kingdom.

RSI values show that France, the United States, India and Spain have the highest degree of specialization in Automation and Circularity technologies. Japan is clearly below average in terms of specialization in this area.

Four of the top ten patent owners have seen a decline in patent family publications since 2018

Figure C34 Automation and Circularity: country comparison, RSI (2000–2023) and growth rates (2018–2023)



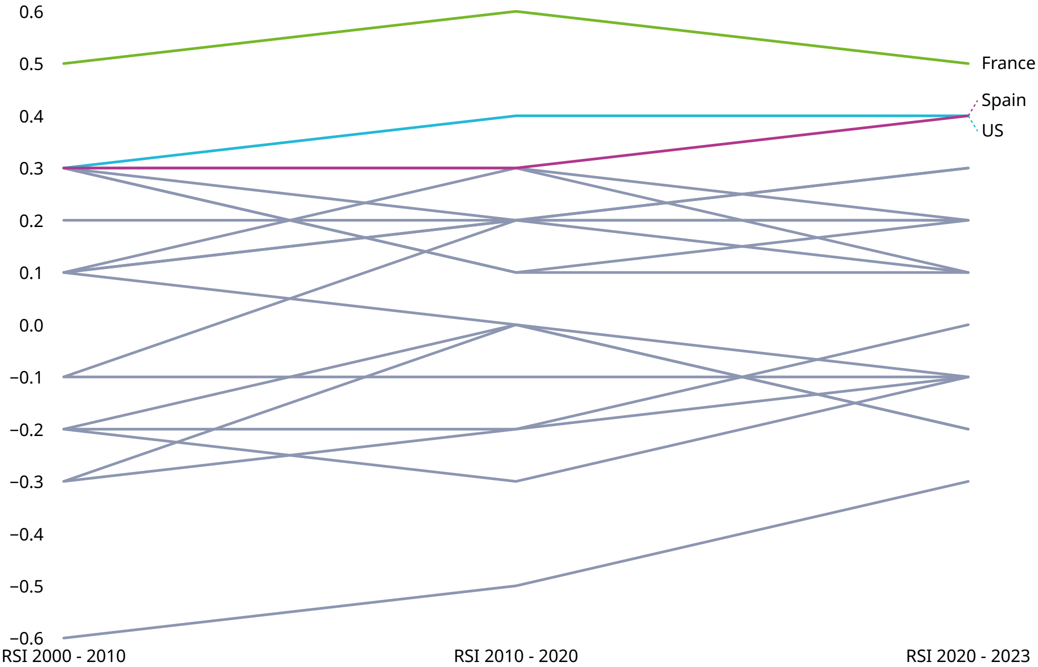
Note: The size of the bubbles shows the number of patent family publications at the country level in the field of Automation and Circularity. The average annual patent growth rates are for 2018–2023, and the Relative Specialization Index (RSI) for the whole period analyzed, 2000–2023.

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

The evolution of RSI values over different time periods since 2000 shows that France's high specialization in Automation and Circularity technologies has remained relatively constant through the years (Figure C35).

RSI values show that France's high specialization in Automation and Circularity technologies has remained relatively constant since 2000

Figure C35 Automation and Circularity: top 20 countries' relative specialization, 2000–2023



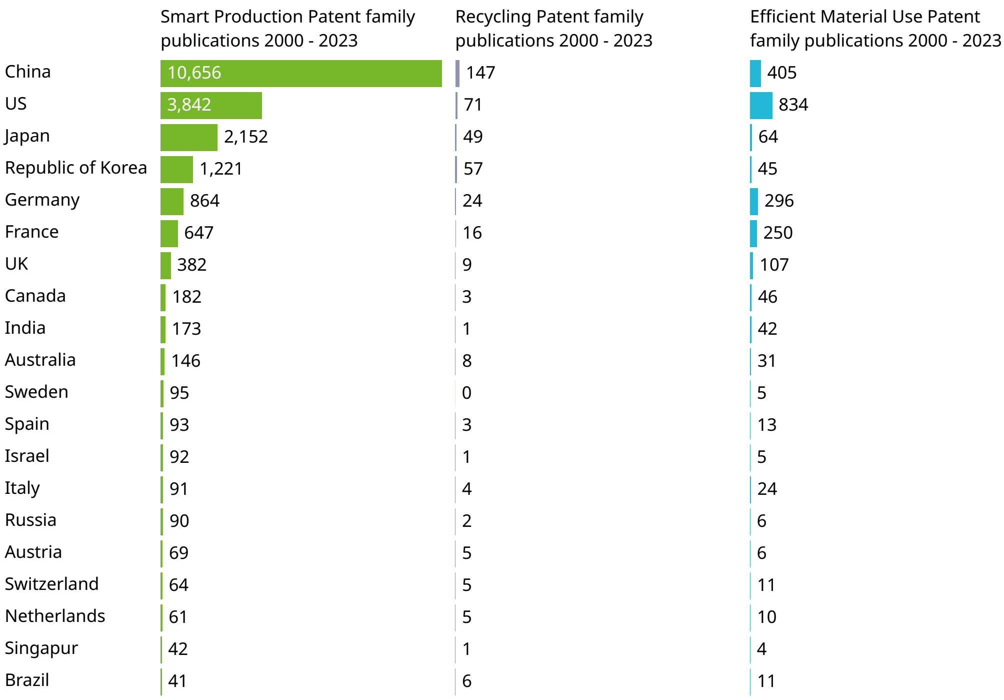
Note: RSI is relative specialization index.
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Analysis of the top research countries in the different subgroups of Automation and Circularity technologies provides the following key results (Figure C36).

- China is the clear technology leader in smart production with more than 10,600 patent family publications. The country has more than twice as many patent family publications as the second-ranked the United States (3,842).
- However, the United States has developed the most patent families in the research field of efficient use of materials. China, Germany and France are also important players in this field.
- China, the United States, the Republic of Korea and Japan are at the forefront of research on recycling in air transport. However, the number of patent family publications remains relatively modest in all these countries.

China is the clear leader in smart production with over 10,600 patent publications, more than double the 3,842 published by the second-ranked US.

Figure C36 Top 20 inventor locations for Automation and Circularity subgroups, 2000–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

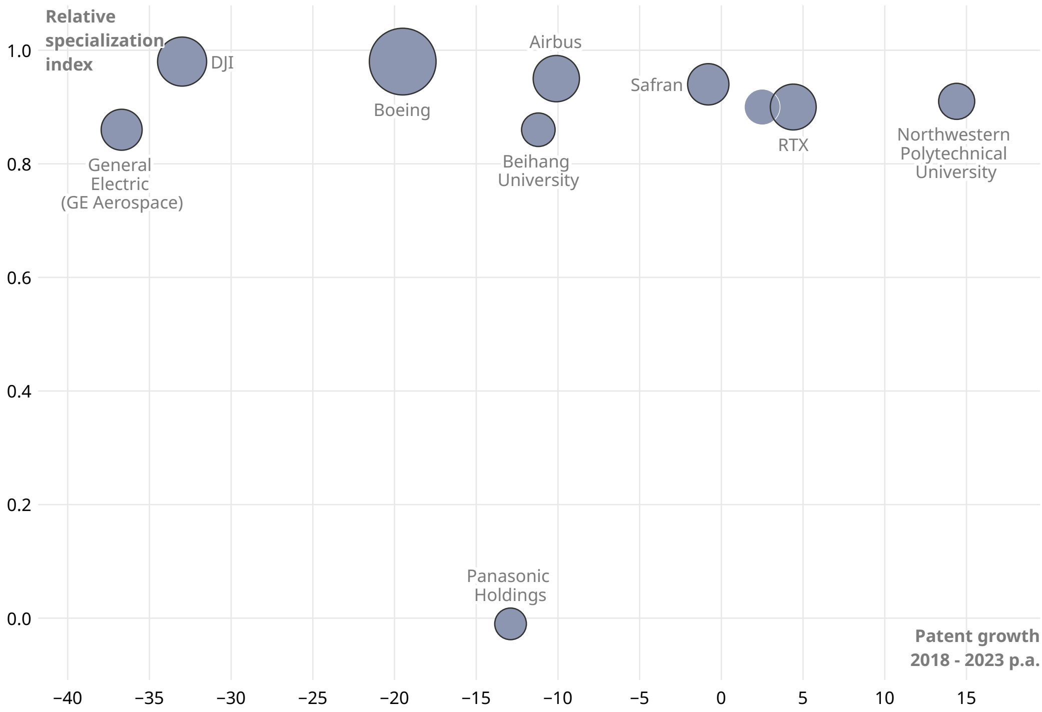
Boeing (1,000 patent family publications between 2000 and 2023), Chinese drone-maker DJI (536), Airbus (476) and RTX (467) are the top research companies in Automation and Circularity technologies in terms of patent family publications (Figure C37). All of these companies have a very high RSI score.

Some companies whose main business focus lies in other industries such as Panasonic also play a relevant role in Automation and Circularity research in air transport. As a consequence, the RSI score of Panasonic is much lower.

In terms of growth rates, the Chinese Northwestern Polytechnical University stands out among the top 10 patent owners, with an annual growth rate in patent family publications of more than 14% since 2018.

The Chinese Northwestern Polytechnical University stands out among the top 10 patent owners, with an annual patent publication growth of over 14% since 2018.

Figure C37: Automation and Circularity: comparison of top patent owners, RSI (2000–2023) and growth rates (2018–2023)



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

With regard to the top patent owners in the three sub-groups of Automation and Circularity technologies, the following results and research examples can be noted (Figure C38):

- Boeing is an innovator in smart production technologies with almost 850 published patent families in this field. For example, this US aircraft manufacturer is using AI-powered robots on its assembly line to automate tasks like drilling, painting and assembly in order to reduce cycle times and enhance productivity. [14]
- Airbus also has published many patent families both in smart production and efficient material use. Airbus is also active in recycling. In 2022, the company initiated the European research project, HELACS (Holistic processes for the cost-effective and sustainable management of End of Life of Aircraft Composite Structures) that focuses on the dismantling and recycling of large composite structures. [15]
- Almost all of DJI's patent families in Automation and Circularity technologies belong to the area of smart production. DJI's drones can be used to better detect manufacturing irregularities or deviations, so as to improve quality control and reduce downtime. [16]
- RTX is the research leader in efficient material use with almost 230 published patent families since 2000. RTX focuses on the development of advanced materials and manufacturing techniques that enhance performance while reducing resource consumption. For example, RTX is leveraging additive manufacturing to optimize designs, shorten production times and produce parts on-demand, thereby minimizing material waste. [17]

14 Linköping University (2018). Materials for more efficient aviation. Available at: https://liu.se/en/news-item/material-for-ett-effektivare-flyg.
15 Airbus (2022). End-of-life Reusing, recycling, rethinking. Available at: https://aircraft.airbus.com/en/newsroom/news/2022-11-end-of-life-reusing-recycling-rethinking.
16 DJI Enterprise (2021). DJI Enterprise's complete guide to drone inspections based on best use cases. Available at: https://enterprise-insights.dji.com/blog/complete-guide-to-drone-inspections.
17 RTX (2023). RTX's Collins Aerospace business opens $14 million additive manufacturing center expansion in West Des Moines, Iowa. Available at: www.rtx.com/news/news-center/2023/07/21/rtxs-collins-aerospace-business-opens-14-million-additive-manufacturing-center.

Boeing is an innovator in smart production technologies with nearly 850 published patents, while RTX leads in efficient material use with almost 230 published patents since 2000.

Figure C38 Top 5 patent owners in the subgroups of Automation and Circularity

Subgroup	Company	Patent Family Publications
Efficient Material Use	Airbus	128
Efficient Material Use	General Electric (GE Aerospace)	142
Efficient Material Use	Boeing	178
Efficient Material Use	Safran	179
Efficient Material Use	RTX	227
Recycling	Safran	4
Recycling	Adeka	5
Recycling	Boeing	5
Recycling	Chinese Academy of Sciences	5
Recycling	Beijing Institute of Technology	7
Smart Production	Nanjing University of Aeronautics	270
Smart Production	Northwestern Polytechnical University	278
Smart Production	Airbus	355
Smart Production	DJI	536
Smart Production	Boeing	849

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Communication and Security

Communication and Security technologies in the air transport field include navigation technologies, low-latency-communication, device-to-device communication, cloud solutions and cybersecurity technologies.

The most important area in terms of patent family publications is clearly navigation technologies. The number of patent family publications in this technology area has increased fifteen-fold from 466 in 2000 to almost 7,300 in 2023 after reaching an even higher peak of 7,800 in 2021(Figure C39). Aviation navigation technologies have evolved significantly over the past decades, improving the safety, efficiency and reliability of aviation. For example, global positioning system (GPS) technology has been enhanced through the integration of multiple satellite navigation systems such as GLONASS, Galileo and BeiDou.[18] Research initiatives such as the FAA's Next Generation Air Transportation System (NextGen) in the United States[19] and the Single European Sky ATM Research (SESAR) in Europe[20] have been instrumental in modernizing air traffic management and navigation. These programs have introduced technologies such as Data Comm and System Wide Information Management (SWIM), that increase efficiency, reduce delays and improve safety. In addition, machine learning and AI are increasingly being applied to navigation and air traffic management with a focus on flight route optimization. Other important advances include the Enhanced Vision Systems (EVS) and the Synthetic Vision Systems (SVS),[21] which provide better visibility and situational awareness in poor weather conditions.

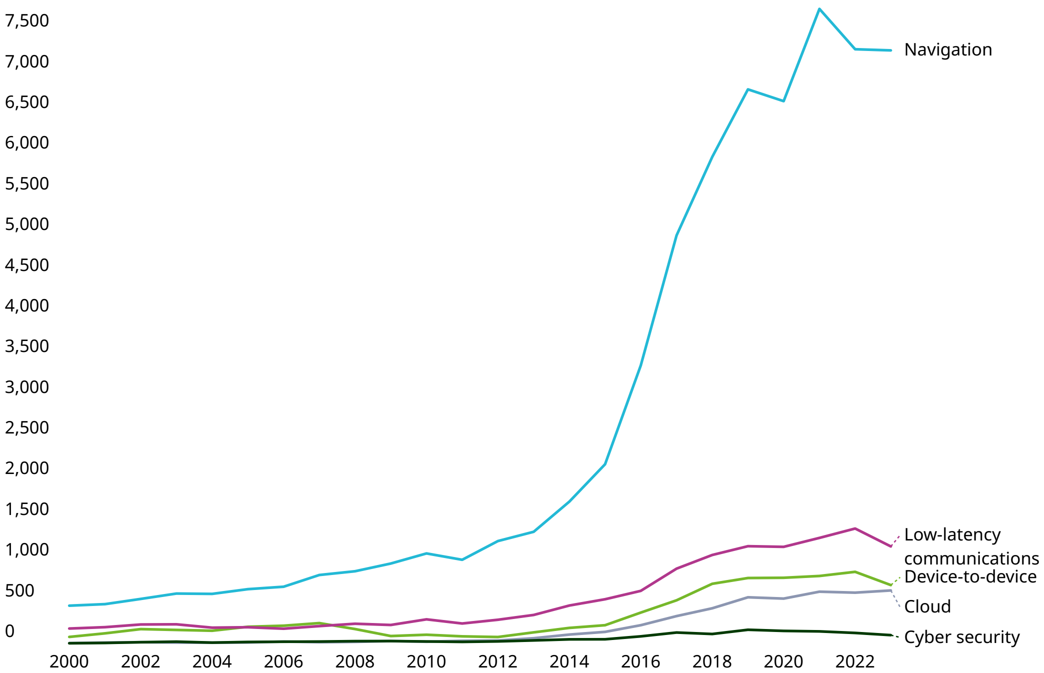
The second most important research area is low-latency-communication, where patent family numbers have grown from less than 200 to around 1,200 between 2000 and 2023. Low latency communication is integral to the effectiveness and safety of navigation technologies in aviation, facilitating real-time data exchange. For example, low latency communication ensures that

18 Thales Aerospace blog (2016). GPS and Galileo: A winning combination for aviation and beyond. Available at: https://onboard.thalesgroup.com/gps-galileo-winning-combination-aviation-beyond.
19 FAA. Next Generation Air Transportation System (NextGen). Federal Aviation Administration. Available at: www.faa.gov/nextgen.
20 SESAR. Discover SESAR. Available at: www.sesarju.eu/discover-sesar.
21 SESAR (2019). Synthetic vision provides approach and taxi guidance to pilots. Available at: www.sesarju.eu/sesar-solutions/enhanced-visual-operations.

information between pilots and air traffic controllers is exchanged in real-time and allows for immediate updates and corrections to flight paths, which is crucial during critical phases of flight such as takeoff and, landing, and during adverse weather conditions. The rollout of 5G networks provides significantly lower latency than previous generations of mobile networks, benefiting aviation, where it can enhance communication between ground systems and aircraft. Advances in satellite communications, including low Earth orbit (LEO) satellites, are reducing latency and improving global coverage, which is particularly beneficial for remote and over-ocean flight operations.

Navigation technologies lead in patent publications, rising from 466 in 2000 to nearly 7,300 in 2023, with a peak of 7,800 in 2021.

Figure C39 Communication and Security: development of global patent family publications, 2000–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Patent family publications for device-to-device technologies in aviation have also increased significantly to over 700 in 2023. Device-to-device communication in aviation plays a pivotal role in enhancing the efficiency, safety and reliability of air transport operations. Key developments include the integration of technologies such as Automatic Dependent Surveillance-Broadcast (ADS-B), which enables aircraft to broadcast their position, velocity, and other critical data directly to other aircraft and ground stations. This real-time sharing of information enhances collision avoidance, optimizes flight paths and improves air traffic management. D2D communication also supports more efficient and safer formation flying and swarming tactics for military and unmanned aerial vehicles (UAVs).

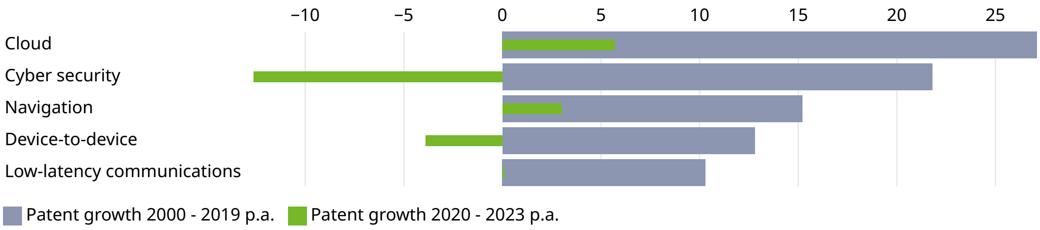
Patent family publications for cloud technologies in air transport increased to around 650 in 2023. Cloud computing enables airlines to store and process vast amounts of data in real time, enabling more informed decision making. For example, predictive maintenance uses cloud-based data analytics to monitor aircraft health and predict potential failures before they occur, thereby reducing downtime and maintenance costs. In addition, cloud technology enables seamless communication and data sharing between different stakeholders, including airlines, airports and air traffic control.

The smallest research area in terms of patent family publications is cybersecurity in air transport. Patent activity has increased only moderately from 4 in 2000 to around 100 in 2023. Nevertheless, cybersecurity plays a critical role owing to the adoption of technologies like cloud computing and advanced navigation and communication systems that expose aviation infrastructure to a wide range of potential cyber threats.[22] Cybersecurity measures are therefore essential to the protection of aircraft navigation and control, passenger data and operational logistics. Key research developments in aviation cybersecurity are focused on improving threat detection and response capabilities. Innovations in AI are being used to develop more sophisticated and adaptive security protocols.[23] Research is also being conducted into developing robust encryption methods and secure communication channels.

Looking at the compound annual growth rates of patent family publications over different time periods, a clear picture emerges. Innovation activity was dynamic in all subcategories between 2000 and 2019, but growth rates have slowed down and even been negative in some technology areas from 2020 onward (Figures C40–C42).

Innovation was dynamic across all subcategories from 2000 to 2019, but growth rates have slowed and turned negative in some areas since 2020.

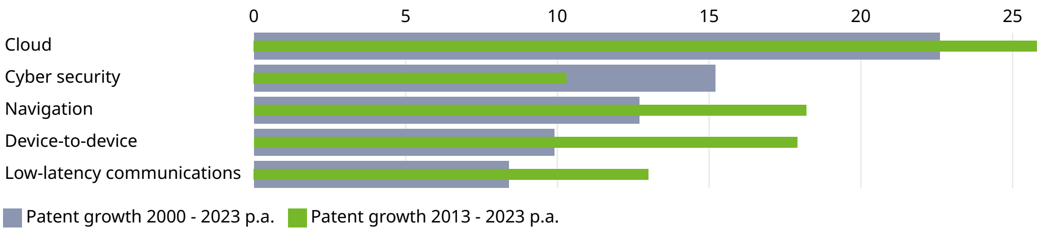
Figure C40 Communication and Security: growth of patent family publications, 2000–2019 and 2020–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Innovation was dynamic across all subcategories from 2000 to 2019, but growth rates have slowed and turned negative in some areas since 2018.

Figure C41 Communication and Security: growth of patent family publications, 2000–2023 and 2013–2023

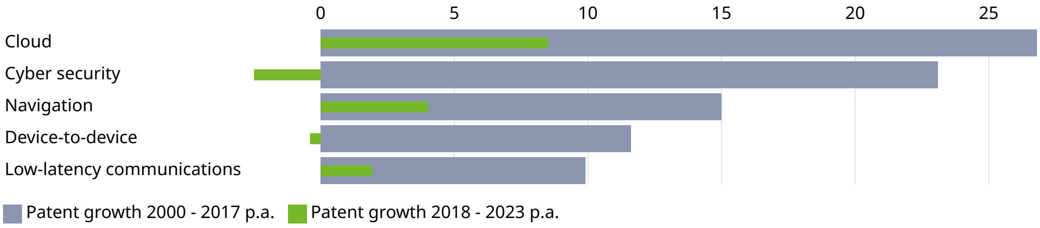


Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

22 Forbes (2023). What role does AI play in enhancing aviation cybersecurity? Available at: www.forbes.com/sites/cognitiveworld/2023/07/29/what-role-does-ai-play-in-enhancing-aviation-cybersecurity.
23 Swiss Cognitive (2024). How artificial intelligence improves aviation cybersecurity. Available at: https://swisscognitive.ch/2024/02/20/how-artificial-intelligence-improves-aviation-cybersecurity.

Innovation was dynamic across all subcategories from 2000 to 2019, but growth rates have slowed and turned negative in some areas since 2020.

Figure C42 Communication and Security: growth of patent family publications, 2000–2017 and 2018–2023



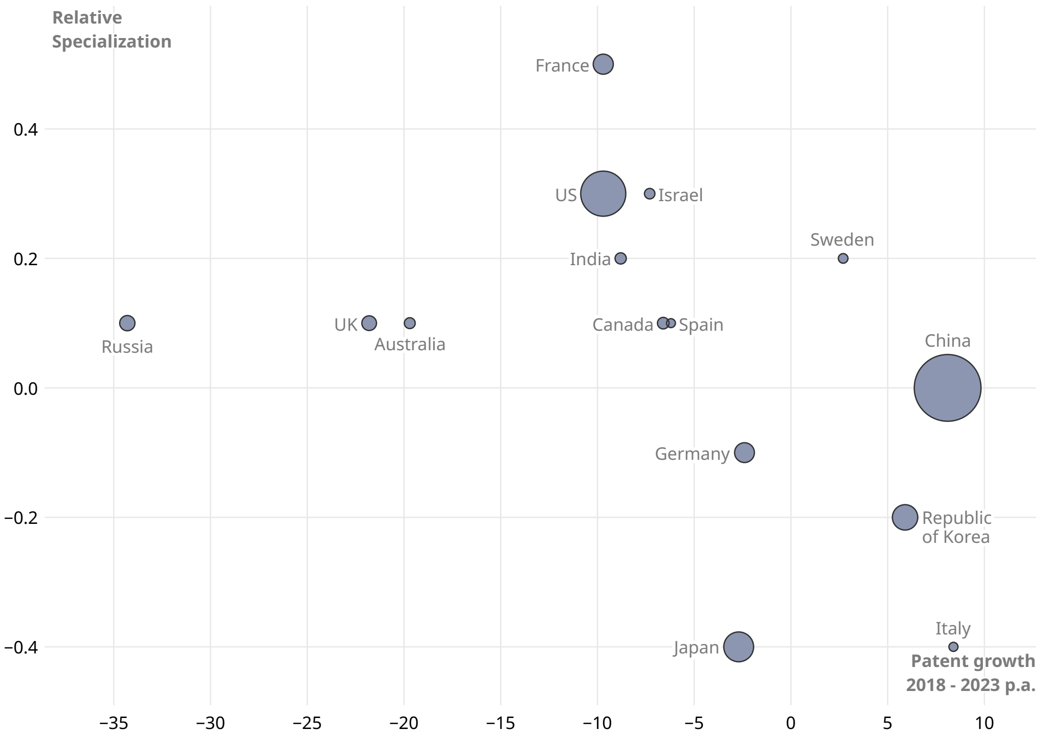
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

A country comparison in the field of Communication and Security technologies shows that China has become responsible for most patent family publications thanks to very high innovation dynamics (Figure C43). The Republic of Korea and Italy have also achieved high growth rates over recent years.

RSI values show France, Israel and the United States having the highest degree of specialization in Communication and Security technologies. Italy and Japan are below average in terms of specialization in Communication and Security technologies.

France, Israel, and the United States have the highest specialization in Communication and Security technologies.

Figure C43 Communication and Security: country comparison (top 15), RSI (2000–2023) and growth rates (2018–2023)



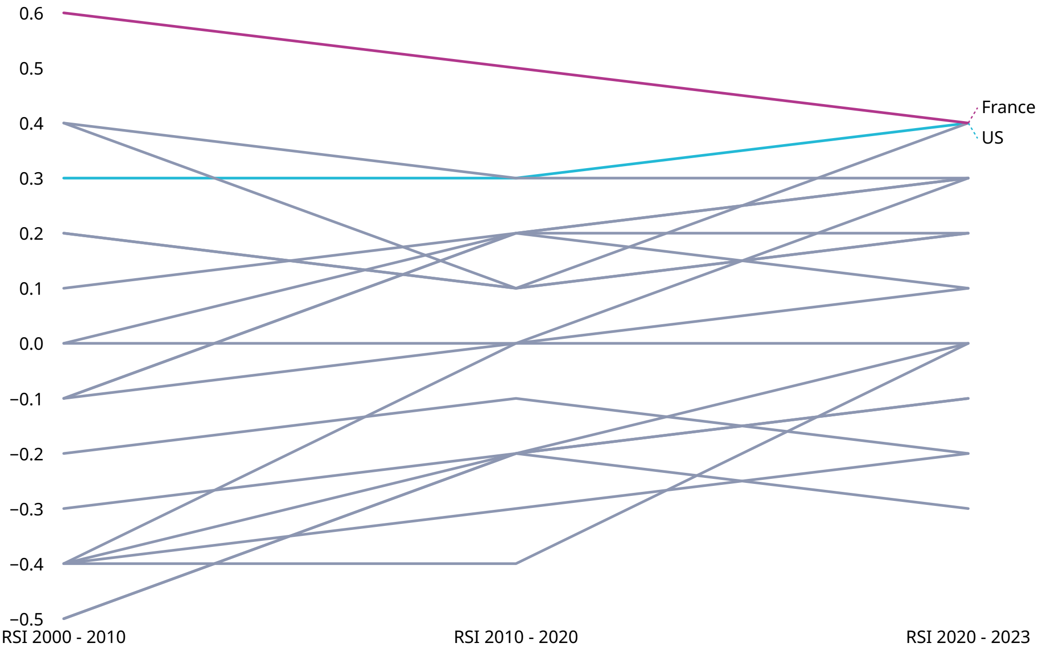
Note: The size of the bubbles shows the number of patent family publications at the country level in the field of Communication and Security technologies. The average annual patent growth rates are for 2018–2023, and the Relative Specialization Index (RSI) for the whole period analyzed, 2000–2023.

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

The evolution of RSI values over different time periods since 2000 shows that France's high specialization in Communication and Security technologies decreased from 0.6 between 2000 and 2010 to 0.4 between 2020 and 2023 (Figure C44).

France's high specialization in Communication and Security technologies dropped from 0.6 in the 2000s to 0.4 in the 2020s.

Figure C44 Communication and Security: top 20 countries' relative specialization, 2000–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

The analysis of the top research countries in the different subgroups of Communication and Security technologies provides the following key results (Figure C45):

- China is the technology leader in navigation and cloud technologies in terms of total patent family publications.
- The United States is ahead in device-to-device communication and cybersecurity.
- China and the United States are at an equal level in low-latency-communication research activities.
- Other key research countries include Japan, the Republic of Korea, Germany and France.

China leads in navigation and cloud technologies, the U.S. in device-to-device communication and cybersecurity, while both are equal in low-latency communication research.

Figure C45 Top 20 inventor locations for Communication and Security subgroups, 2000–2023

	Device-to-device Sum 2000 - 2023	Navigation Sum 2000 - 2023	Cloud Sum 2000 - 2023	Cyber security Sum 2000 - 2023	Low-latency communication Sum 2000 - 2023
US	3,147	12,426	1,306	685	4,689
China	2,703	33,227	2,746	397	4,697
Japan	771	6,377	154	57	952
Republic of Korea	566	4,455	157	63	848
Germany	488	2,343	93	66	615
France	288	2,446	79	133	597
UK	253	1,038	72	50	405
India	188	493	90	33	148
Canada	186	486	73	27	230
Australia	136	471	53	33	152
Sweden	93	311	17	4	95
Israel	71	454	26	25	118
Finland	48	128	11	2	48
Spain	42	233	11	12	67
Netherlands	37	164	7	4	43
Switzerland	29	204	18	18	54
Russia	26	1,452	8	10	249
Italy	24	246	16	7	78
Austria	22	158	6	3	29
Brazil	12	118	8	2	25

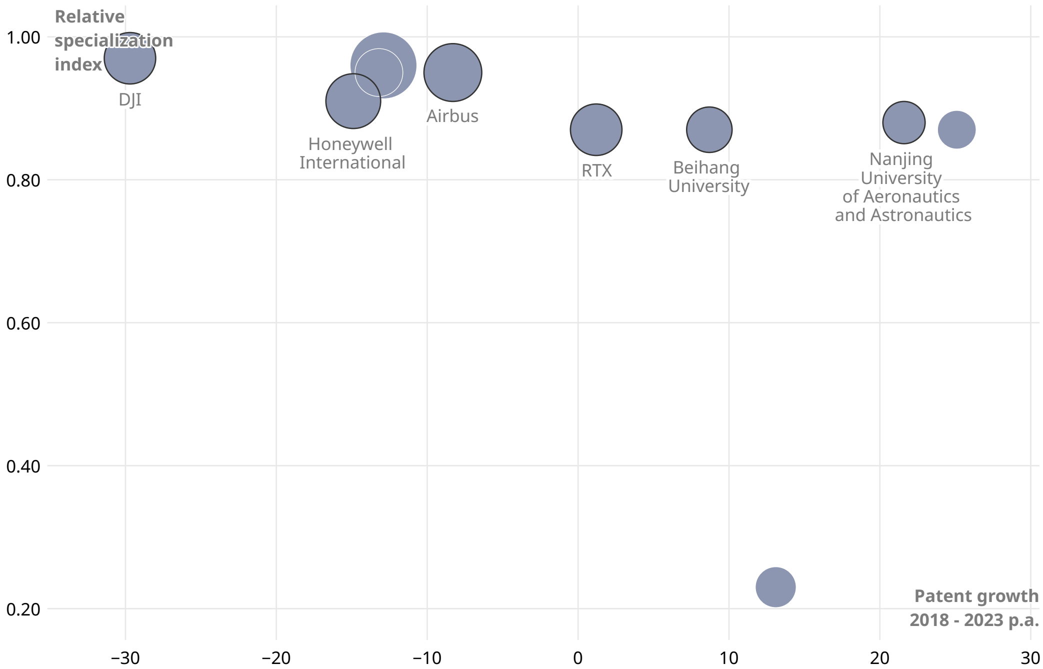
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Boeing (2,165 patent family publications between 2000 and 2023), Airbus (1,621), Honeywell (1,453), RTX (1,283), DJI (1,279) and Thales (1,100) are the top research companies in Communication and Security technologies in terms of patent family publications (Figure C46). All of these companies have a very high RSI score. The four Chinese research organizations Beihang University, Nanjing University of Aeronautics and Astronautics, Northwestern Polytechnical University and the Chinese Academy of Sciences have also developed large patent portfolios in Communication and Security technologies.

In terms of growth rates, all four of the aforementioned Chinese research institutions have achieved high patent growth rates since 2018. In contrast, the patenting activity of the top research enterprises has declined over the same period, the only exception being RTX, which has maintained its patenting activity at a constant level.

Chinese research institutions dominate the Automation and Circularity landscape, accounting for 9 of the top 10 applicants.

Figure C46 Communication and Security: comparison of top patent owners, RSI (2000–2023) and growth rates (2018–2023)



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

With regard to the top patent owners in the five sub-groups, the following results and research examples can be noted (Figure C47):

- Boeing is a top researcher in all Communication and Security technologies. Boeing's lead is particularly strong in device-to-device communication, with 315 patent family publications since 2000 (almost twice as many as Honeywell, which ranks second with 159).
- Chinese drone maker DJI is mainly pursuing research projects in navigation technologies. DJI is advancing autonomous navigation, enabling drones to operate without human intervention. This involves integrating sensors, cameras and algorithms to navigate and respond to their environment.
- Airbus is very active in research and development of navigation technologies. For example, Airbus is developing the new V3 generation of the satellite-based augmentation system EGNOS (European Geostationary Navigation Overlay Service) The EGNOS V3 is designed to add crucial security features for applications such as aircraft navigation and landing.[24] It will also introduce new services based on multiple frequencies from multiple constellations (GPS, Galileo).
- Honeywell is also a leading research company in all Communication and Security technologies. For example, this US company provides hardware and software systems for aircraft that use security measures to provide multifactor authentication, encryption and data integrity.[25]

24 Airbus (2022). Airbus achieves key milestone on EGNOS European satellite-based navigation augmentation system. Available at: www.airbus.com/en/newsroom/press-releases/2022-12-airbus-achieves-key-milestone-on-egnos-european-satellite-based.
25 Honeywell Aerospace Technologies. Aerospace cybersecurity solutions. Available at: https://aerospace.honeywell.com/us/en/products-and-services/product/services/aerospace-cybersecurity-solutions.

Boeing is a top researcher in all Communication and Security technologies.

Figure C47 Top 5 patent owners in the subgroups of Communication and Security

Subgroup	Company	Country	Patent Family Publications
Device-to-Device	Panasonic Holdings	Japan	132
Device-to-Device	RTX	US	142
Device-to-Device	Airbus	EU	148
Device-to-Device	Honeywell International	US	159
Device-to-Device	Boeing	US	315
Navigation	RTX	US	1,031
Navigation	Honeywell International	US	1,203
Navigation	DJI	China	1,221
Navigation	Airbus	EU	1,240
Navigation	Boeing	US	1,382
Cloud	Nanjing University of Aeronautics and Astronautics	China	49
Cloud	DJI	China	76
Cloud	State Grid Corp of China	China	85
Cloud	Honeywell International	US	88
Cloud	Boeing	US	107
Cyber Security	RTX	US	40
Cyber Security	Thales	France	50
Cyber Security	Honeywell International	US	52
Cyber Security	Airbus	EU	52
Cyber Security	Boeing	US	119
Low-Latency Communication	Honeywell International	US	217
Low-Latency Communication	Chinese Academy of Sciences	China	256
Low-Latency Communication	Airbus	EU	303
Low-Latency Communication	Alphabet	US	303
Low-Latency Communication	Boeing	US	676

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Human–Machine Interface

Human–Machine Interface (HMI) technologies in the air transport field include the areas VR/AR/metaverse, Touch Display/Data gloves, Face recognition, Speech recognition and Head-up-displays.

VR/AR/metaverse has become the most important subgroup of HMI technologies in Air transport in recent years. The number of patent family publications in this technology area has increased from only 23 in 2000 to more than 350 in 2023 (Figure C48). The integration of VR/AR/metaverse in aviation improves training, operations and maintenance. Recent research focuses on the development of virtual training environments for pilots and maintenance crews, providing realistic simulations that improve skills and safety without the risks associated with real-life training.[26] Additionally, AR is being used for real-time navigation and cockpit assistance, improving situational awareness and operational efficiency.

The number of patent families published in the area of touch displays/data gloves has increased from 27 in 2000 to 226 in 2023. Advanced touchscreens streamline cockpit operations by consolidating multiple control functions into a single, intuitive interface, thereby improving efficiency and reducing pilot workload. Meanwhile, haptic-feedback data gloves provide tactile sensations for virtual objects, aiding remote training.

Facial recognition patent families have increased from only 2 in 2000 to more than 150 in 2023. Facial recognition technology enhances security, streamlines passenger processing and improves the overall travel experience. Airports are increasingly using facial recognition systems for tasks such as check-in, boarding and security screening.[27] However, the implementation of facial recognition in aviation also raises privacy concerns and regulatory challenges.

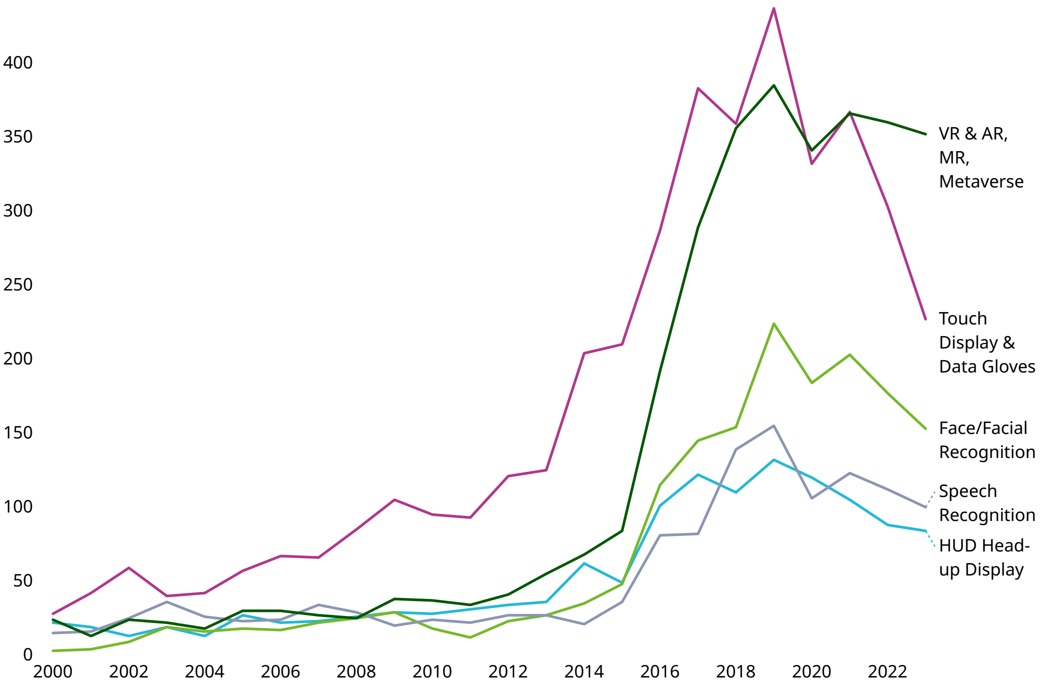
The number of patent family publications for speech recognition in air transport remains has risen from 14 in 2000 to 99 in 2023. Recent advances have focused on improving automatic speech recognition (ASR) systems for air traffic control and pilot interaction. Moreover, speech recognition can significantly speed up inspections and maintenance operations. Ground crew teams can perform external aircraft inspections hands-free, simply using their voice to capture observations and record data.[28]

The number of patent families published for aviation head-up displays has increased from 21 in 2000 to 83 in 2023. These displays project essential flight data and navigation information onto a transparent screen in the pilot's line of sight, allowing the pilot to maintain focus outside the cockpit while accessing critical information. Used for decades by military pilots, head-up displays are now commonplace in large commercial and private aircraft.[29]

26 Airforce Technology (2023). AR and VR's role in aviation. Available at: www.airforce-technology.com/analyst-comment/ar-vr-role-aviation/?cf-view.
27 Future Travel Experience (2024). Berlin Brandenburg Airport introduces BER Biometrics – "another building block towards a smart airport of the future" Available at: www.futuretravelexperience.com/2024/07/berlin-brandenburg-airport-introduces-ber-biometrics-another-building-block-towards-a-smart-airport-of-the-future.
28 aiOla (2024). The future of AI in aviation 2024: A flight path to success. Available at: https://aiola.com/blog/future-of-ai-in-aviation/#:~:text=aiOla%20will%20gather%20the%20essential,safety%20checks%20and%20improving%20punctuality.
29 Radiant Vision Systems (2021). Safety in the air: The latest in aviation head-up displays (HUDs). Available at: www.radiantvisionsystems.com/blog/safety-air-latest-aviation-head-displays-huds.

VR/AR/metaverse has become the leading subgroup of HMI technologies in air transport, with patent publications rising from 23 in 2000 to over 350 in 2023.

Figure C48 Human–Machine Interface: development of global patent family publications, 2000–2023

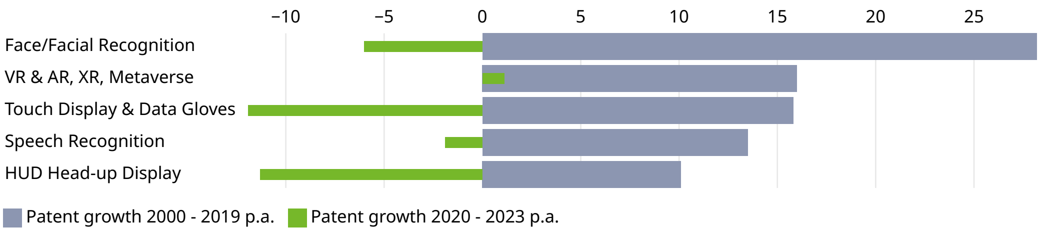


Note: VR is virtual reality, AR is augmented reality, XR is extended reality.
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Patent growth in HMI technologies was very dynamic in all subgroups between 2000 and 2019. However, from 2020 onward, patent growth has been negative in all HMI technologies except VR/AR/metaverse (Figures C49–C51).

Patent growth in HMI technologies was highly dynamic across all subgroups from 2000 to 2019 unlike last 3 years.

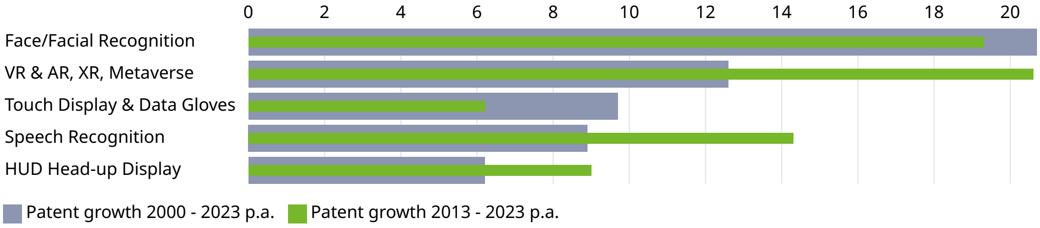
Figure C49 Human–Machine Interface: growth of patent family publications, 2000–2019 and 2020–2023



Note: VR is virtual reality, AR is augmented reality, XR is extended reality.
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Since 2020, patent growth has declined in all HMI technologies except VR/AR/metaverse.

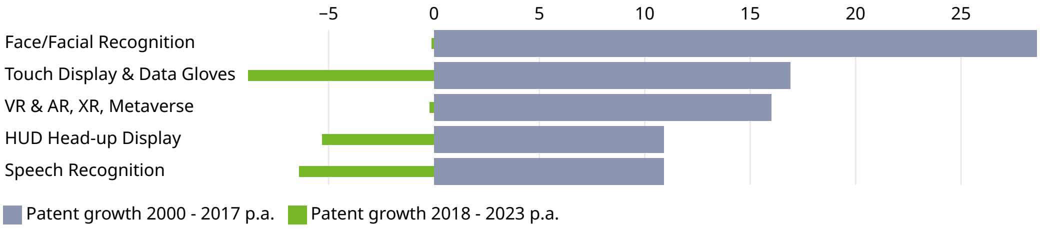
Figure C50 Human–Machine Interface: growth of patent family publications, 2000–2023 and 2013–2023



Note: VR is virtual reality, AR is augmented reality, XR is extended reality.
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Since 2018, patent growth has declined in all HMI technologies.

Figure C51 Human–Machine Interface: growth of patent family publications, 2000–2017 and 2018–2023



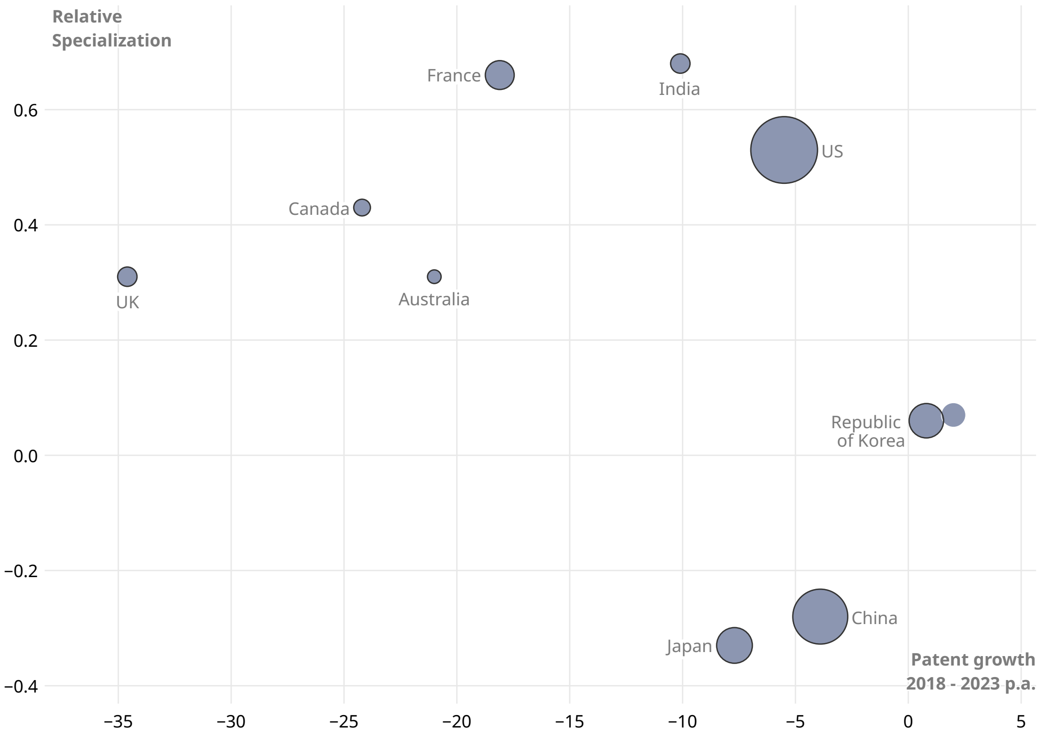
Note: VR is virtual reality, AR is augmented reality, XR is extended reality.
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

A country comparison in the field of HMI technologies shows that the United States is the leading country in terms of sheer volume of patent publications. However, patenting activity has declined in most countries in since 2018 (Figure C52). Patent family publications have only risen slightly in the Republic of Korea and Germany.

RSI values show that France, India and the United States have the highest degree of specialization in HMI technologies. Japan and China are well below average in terms of specialization in this area.

Only Norway has a higher RSI than the Republic of Korea over the period from 2000 to 2023.

Figure C52 Human–Machine Interface: country comparison, RSI (2000–2023) and growth rates (2018–2023)



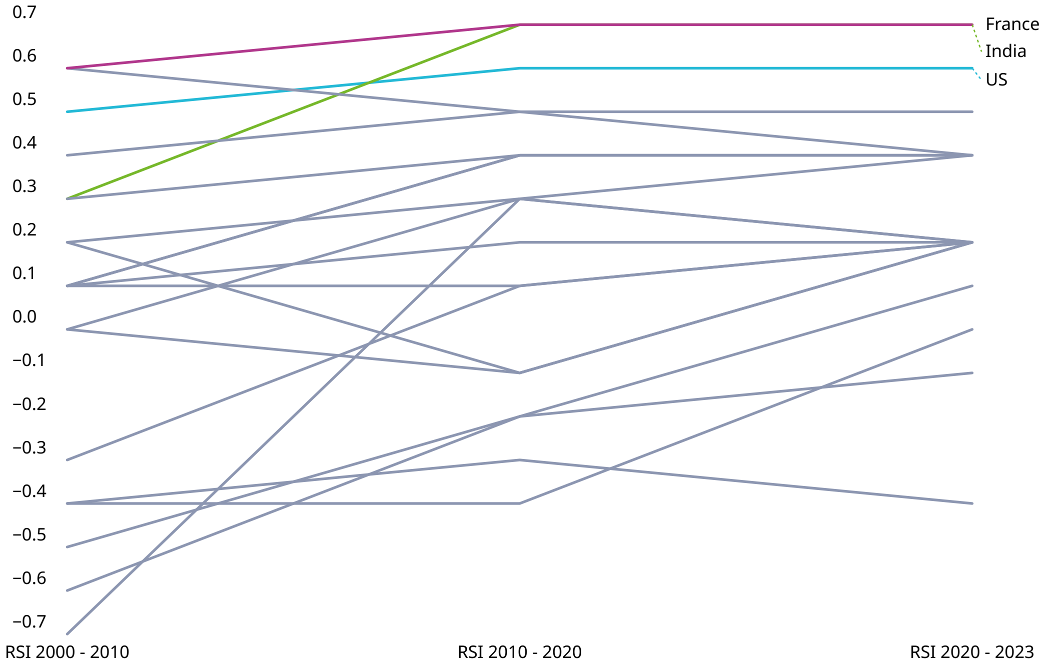
Note: The size of the bubbles shows the number of patent family publications at the country level in the field of HMI technologies. The compound annual patent growth rates are for 2018–2023, and the Relative Specialization Index (RSI) for the whole period analyzed, 2000–2023.

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

The evolution of RSI values over different time periods since 2000 shows that India and the United States have significantly increased their research focus on HMI technologies in relative terms over time (Figure C53). In addition, France has kept a high level of research specialization in these technologies since 2000.

India and the U.S. have increased their focus on HMI technologies since 2000, while France has maintained high specialization.

Figure C53 Human–Machine Interface: top 20 countries' relative specialization, 2000–2023



Note: RSI is relative specialization index.
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

An analysis of the top research countries in the different subgroups of HMI technologies reveals the following key findings (Figure C54):

- The United States is the research leader in all five HMI technologies. The United States lead is particularly strongly in respect to head-up displays.
- China is catching up in most HMI technologies. It is particularly dominant in speech recognition, publishing almost as many patent families as the United States.
- The Republic of Korea is especially active in VR/AR/metaverse research.
- France has developed the second most patent families in head-up displays.

The U.S. leads in all HMI technologies, especially head-up displays, while China is catching up and nearly matches the U.S. in speech recognition patents.

Figure C54 Top 20 inventor locations for Human–Machine Interface subgroups, 2000–2023

The U.S. leads in all HMI technologies, especially head-up displays, while China is catching up and nearly matches the U.S. in speech recognition patents.

Figure C55 Top 20 inventor locations for Human–Machine Interface subgroups, 2000–2023

	Face Recognition Patent family publications 2000 - 2023	VT/Metaverse Patent family publications 2000 - 2023	Touch Display&Data Gloves Patent family publications 2000 - 2023	Head-up Display Patent family publications 2000 - 2023	Speech Recognition Patent family publications 2000 - 2023
US	717	1,137	1,655	505	465
China	452	876	835	170	450
Japan	253	201	472	106	113
France	38	171	369	173	32
Republic of Korea	102	416	365	149	107
Germany	43	159	205	75	43
India	30	61	152	26	60
UK	46	97	116	56	26
Canada	26	79	93	26	27
Australia	41	35	46	7	12
Israel	36	38	39	31	12
Netherlands	6	17	22	7	0
Finland	4	11	20	5	0
Russia	6	35	20	8	3
Switzerland	13	19	19	8	6
Spain	5	15	14	4	2
Italy	0	15	14	8	6
Sweden	8	13	9	8	0
Singapur	6	10	7	2	7
Austria	8	20	7	5	2

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

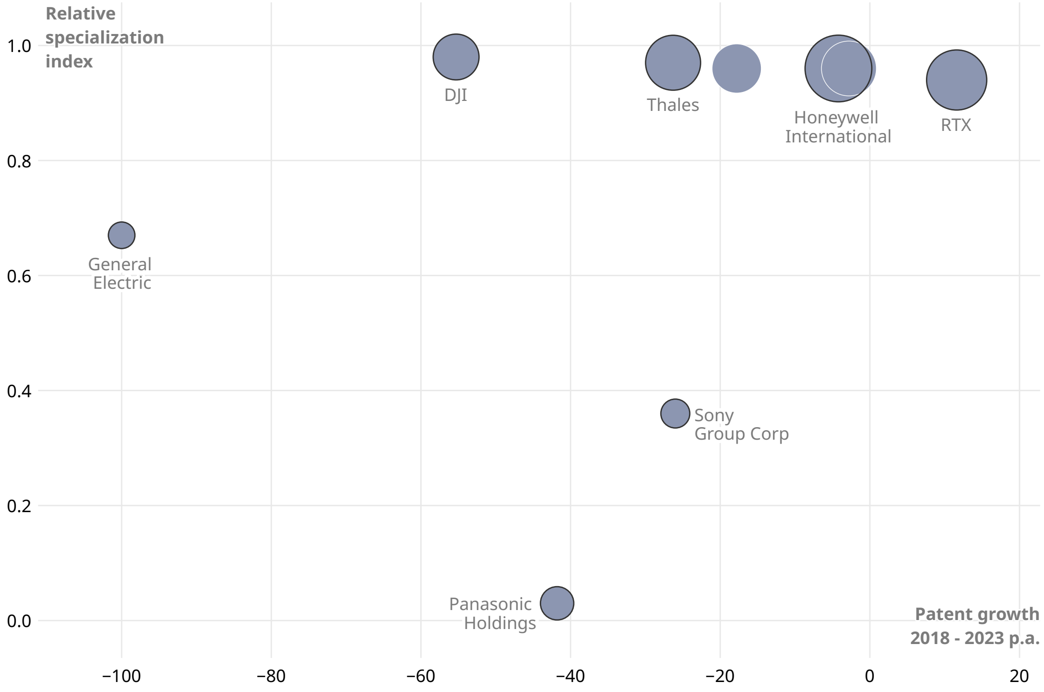
Honeywell (372 patent family publications between 2000 and 2023), RTX (302) and Thales (266) are the top research companies in HMI technologies in terms of patent family publications (Figure C55). All of these companies have a very high RSI score.

Some companies whose main business focus is in other industries, such as Panasonic, also play a relevant role in HMI research in aviation. As a result, Panasonic's RSI score is much lower.

In terms of growth rates, RTX stands out among the top patent owners, being the one company with a positive patent growth rate since 2018.

RTX stands out among top patent owners with the only positive growth rate since 2018.

Figure C55 Human–Machine Interface: comparison of top patent owners, RSI (2000–2023) and growth rates (2018–2023)



Note: RSI is relative specialization index.
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

With regard to the top patent owners in the five sub-groups of HMI technologies, the following results and research examples can be noted (Figure C56):

- DJI is an innovator in facial recognition and AR/VR/metaverse technologies. For example, DJI's Virtual Flight app and VR headsets allow drone pilots to practice at home or the office before taking off a real drone.[30]
- Honeywell is a key research company in speech recognition, touch displays and data gloves and head-up-displays. The company acquired Saab Technology, the head-up-display division of Swedish aerospace and defense company Saab, in 2023. It has integrated head-up-displays into its various avionics offerings, for example into its new modular flight deck Anthem which also incorporates touch displays as well as gesture-based methods.[31] [32]

30 Radiant Vision Systems (2021). Safety in the air: The latest in aviation head-up displays (HUDs). Available at: www.radiantvisionsystems.com/blog/safety-air-latest-aviation-head-displays-huds.
31 Honeywell (2023). Honeywell bringing heads-up displays to aircraft cockpits through acquisition of Saab Technology. Available at: www.honeywell.com/us/en/press/2023/06/honeywell-bringing-heads-up-displays-to-aircraft-cockpits-through-acquisition-of-saab-technology.
32 Honeywell Aerospace Technologies. Your cockpit, your way with Honeywell Anthem. Available at: https://aerospace.honeywell.com/us/en/about-us/blogs/your-cockpit-your-way-honeywell-anthem.

DJI is the leading innovator in face recognition and AR/VR/Metaverse technologies.

Figure C56 Top 5 patent owners in the subgroups of HMI, 2000–2023

Subgroup	Company	Patent Family Publications
Face Recognition	Kubota	21
Face Recognition	NEC	21
Face Recognition	Panasonic Holdings	23
Face Recognition	Sony Group	25
Face Recognition	DJI	42
VR/Metaverse	RTX	59
VR/Metaverse	Thales	61
VR/Metaverse	Airbus	61
VR/Metaverse	DJI	90
VR/Metaverse	Boeing	105
Touch Displays & Data Gloves	Airbus	140
Touch Displays & Data Gloves	Boeing	163
Touch Displays & Data Gloves	Thales	168
Touch Displays & Data Gloves	RTX	191
Touch Displays & Data Gloves	Honeywell International	257
Head-up Displays	BAE Systems	46
Head-up Displays	Airbus	52
Head-up Displays	Honeywell International	55
Head-up Displays	Thales	91
Head-up Displays	RTX	129
Speech Recognition	Thales	15
Speech Recognition	Boeing	17
Speech Recognition	RTX	21
Speech Recognition	Panasonic Holdings	26
Speech Recognition	Honeywell International	99

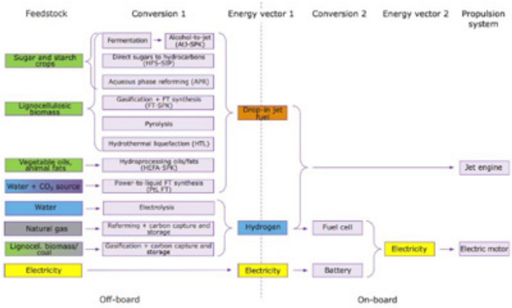
Note: VR is virtual reality.
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Emerging technology in detail: sustainable aviation fuel

Sustainable aviation fuels (SAF) represents a significant advancement in reducing the environmental impact of air transportation. SAF is produced from renewable resources, such as biomass, waste oils and agricultural residues, providing an alternative to conventional jet fuels derived from fossil fuels.[1] Currently, demand for aviation fuel is dominated by jet kerosene, with SAFs accounting for less than 0.1% of all aviation fuels consumed. Manufacturers and operators are increasingly testing flights entirely fuelled by SAF, that be deployed in current infrastructure, engines and aircraft with minor adjustments to fuel delivery equipment. However, planned production capacities will provide just 1–2% of jet fuel demand by 2027. Increasing SAF use in aviation to 10% by 2030 in line with the Net Zero Scenario will require a significant ramp-up of investment in capacity to produce SAF plus supportive policies in respect to fuel tax and low-carbon fuel standards.[2]. The adoption of SAFs is crucial if the aviation industry is to achieve its sustainability goals, reduce greenhouse gas emissions and mitigate climate change impacts.[3]

There are several types of SAF currently under development and in use, each with unique characteristics and production processes. Biofuels are derived from biological materials, such as vegetable oils, animal fats and waste greases (Figure C57). Examples include hydroprocessed esters and fatty acids (HEFA) and Fischer-Tropsch (FT) fuels. Synthetic fuels, or e-fuels, are produced through chemical processes using renewable energy sources, such as wind or solar power, to generate hydrogen, which is then combined with carbon dioxide to create liquid hydrocarbons. Alcohol-to-Jet (ATJ) fuels are produced by converting alcohols, such as ethanol or butanol, into jet fuel through a chemical process.

Figure C57 Alternative aviation fuel routes



Source: Bauen et al., 2020.

The core benefits of SAF include reduced greenhouse gas emissions, improved air quality and enhanced energy security. SAF can reduce life cycle greenhouse gas emissions by up to 80% compared to conventional jet fuel.[4] For example, the Fischer-Tropsch (FT) and HEFA pathways have shown potential in reducing CO_2 emissions by between 50–90%.[5] Additionally, SAF

1 Bauen, A., N. Bitossi, L. German, A. Harris and K. Leow (2020). Sustainable aviation fuels: Status, challenges and prospects of drop-in liquid fuels, hydrogen and electrification in aviation. Johnson Matthey Technology Review, 64(3), 263–278.
2 IEA (2023). Aviation. International Energy Agency. Available at: www.iea.org/energy-system/transport/aviation
3 Chiaramonti, D. (2019). Sustainable aviation fuels: The challenge of decarbonization. Energy Procedia, 158, 1202–1207.
4 IATA (2024). Developing sustainable aviation fuel (SAF). International Air Transport Association. Available at: www.iata.org/en/programs/environment/sustainable-aviation-fuels.
5 Chiaramonti, D. (2019). Sustainable aviation fuels: The challenge of decarbonization. Energy Procedia, 158, 1202–1207.

contributes to improved air quality by producing fewer particulate emissions and sulfur oxides. By diversifying fuel sources, SAF enhances energy security and reduces reliance on fossil fuels.[6] The use of local and renewable feedstocks for SAF production can mitigate the risks associated with geopolitical instability and fluctuating oil prices.[7] The development and scaling of SAF production can also create new economic opportunities, including job creation within the agricultural, industrial and technological sectors.[8]

Despite its their advantages, SAF has several current limitations. The production costs of SAFs are higher compared to conventional jet fuels, primarily due to the limited availability of feedstock and the complexity of the production process. Additionally, there are technical challenges related to the compatibility of SAFs with existing aircraft engines and fueling infrastructure. Ensuring a consistent supply of high-quality feedstocks is also a significant challenge.[9] SAF currently has a higher production cost than conventional aviation fuels. This is mainly due to the high costs of feedstock, a complex production processes and the need for extensive certification.[10] The ASTM certification process, necessary for ensuring the safety and compatibility of new fuels with existing aircraft, is both time-consuming and expensive. The availability of sustainable feedstocks is a major concern. Large-scale production of SAF requires a significant quantity of biomass, which can compete with food production and other land uses.[11] There are also technical challenges in integrating SAF into existing fueling infrastructure and aircraft engines. Ensuring the stability and performance of SAFs under various operating conditions is critical.[12] Significant investments are required to scale up SAF production to a commercial levels. This includes building new biorefineries and upgrading existing facilities to process different types of feedstocks.[13]

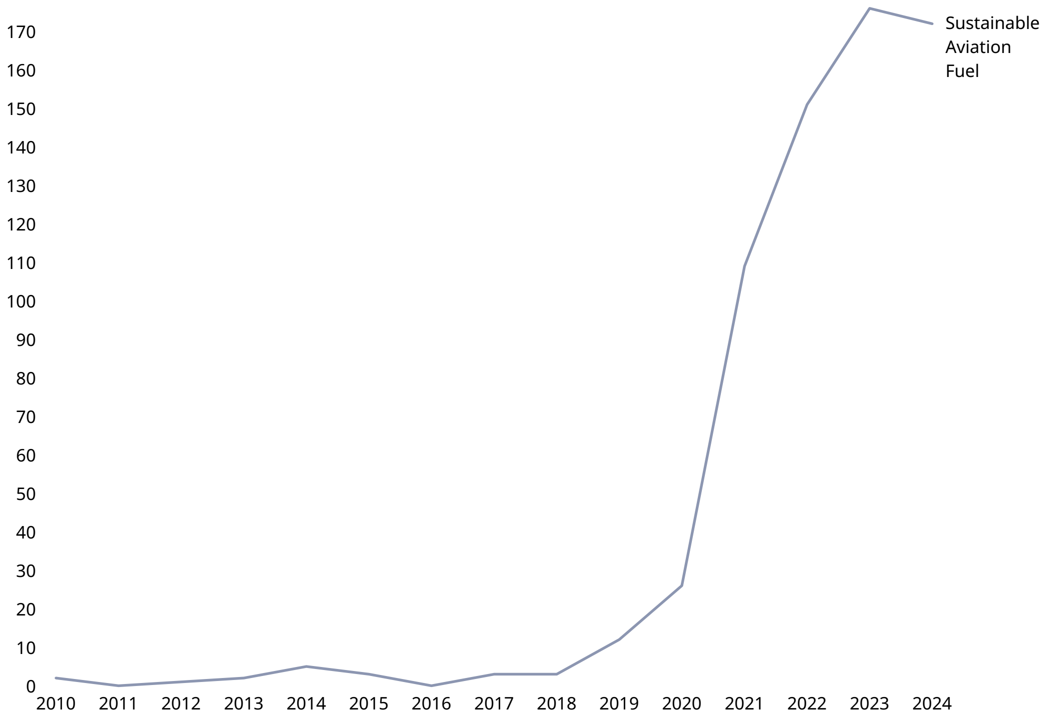
Sustainable aviation fuels: scientific publications

The scientific community has shown increasing interest in SAF, as evidenced by the growing number of publications on the topic. Research focuses on improving production processes, assessing environmental impacts and enhancing the performance of SAFs in aviation applications. Figure C58 displays the number of scientific documents related to SAFs published annually from 2009 to 2024. Data shows there has been a steady increase in the number of publications, with a significant surge starting around 2020. This trend indicates a growing interest in SAF and its potential to transform the aviation industry.

6 IEA (2023). Aviation. International Energy Agency. Available at: www.iea.org/energy-system/transport/aviation.
7 Chiaramonti, D. (2019). Sustainable aviation fuels: The challenge of decarbonization. Energy Procedia, 158, 1202–1207.
8 Bauen, A., N. Bitossi, L. German, A. Harris and K. Leow (2020). Sustainable aviation fuels: Status, challenges and prospects of drop-in liquid fuels, hydrogen and electrification in aviation. Johnson Matthey Technology Review, 64(3), 263–278.
9 Chiaramonti, D. (2019). Sustainable aviation fuels: The challenge of decarbonization. Energy Procedia, 158, 1202–1207.
10 Shehab, M., K. Moshammer, M. Franke and E. Zondervan (2023). Analysis of the potential of meeting the EU's sustainable aviation fuel targets in 2030 and 2050. Sustainability, 15(12), 9266.
11 ICAO (2018). Feasibility Study on the Use of Sustainable Aviation Fuels. International Civil Aviation Organization. Available at: www.icao.int/environmental-protection/Documents/FeasabilityStudy_Kenya_Report-Web.pdf.
12 Chiaramonti, D. (2019). Sustainable aviation fuels: The challenge of decarbonization. Energy Procedia, 158, 1202–1207.
13 Chiaramonti, D. (2019). Sustainable aviation fuels: The challenge of decarbonization. Energy Procedia, 158, 1202–1207.

A steady increase in publications, with a significant surge starting around 2020, indicating growing interest in SAFs and their potential to transform the aviation industry

Figure C58 Development of global scientific publications related to sustainable aviation fuel, 2009–2023

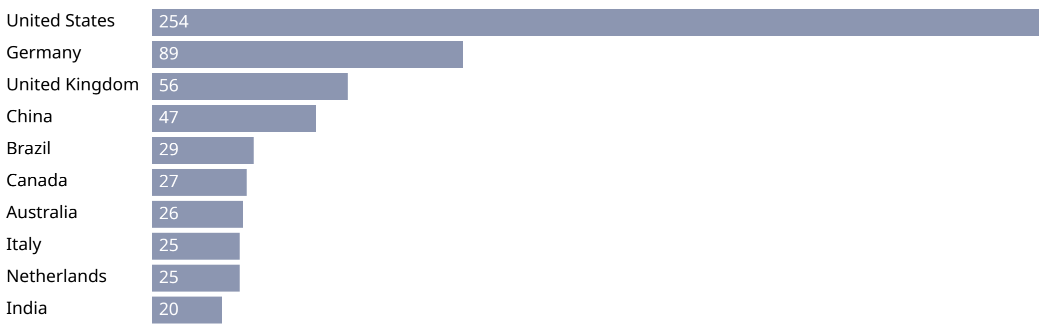


Source: WIPO, based on publication data from Scopus.

Figure C59 shows the number of scientific publications related to SAF by country. The United States leads with a significant number of publications, followed by European countries Germany and the United Kingdom. China, Brazil and Canada also contribute substantially to the research effort in this field.

The United States leads with a significant number of publications, followed by European countries such as Germany and the United Kingdom

Figure C59 Origin countries for scientific publications related to sustainable aviation fuel



Source: WIPO, based on publication data from Scopus.

Sustainable aviation fuel: patent data

Patenting activity in the field of SAF already increased at the end of the 2000s peaking in 2010 at 115 patent families (Figure C60). In the years that followed, patenting activity declined, but reached a new height in 2023 at 156 patent family publications.

Patenting in sustainable aviation fuels rose in the late 2000s, peaking at 115 families in 2010, then declined before hitting a new high of 156 in 2023

Figure C60 Development of global patent family publications related to sustainable aviation fuel, 2000–2023

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

At a country level, most patent family publications were developed in the United States (Figure C61). China, Germany, Japan and France are other important research locations.

The US leads in patent publications, with China, Germany, Japan and France also key research hubs

Figure C61 Patent family publications related to sustainable aviation fuel, 2000–2023

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Sustainable aviation fuel: patent examples

Leading companies in the aviation and energy sectors, such as Boeing, Airbus and Neste, are at the forefront of patent filings, focusing on various aspects of SAF technology, including producing renewable aviation fuel, plant infrastructure as well as refuelling aircraft with SAF.

The core idea of patent WO2023126564A1 from Neste is to develop a method for producing SAF through a combination of bio-based feedstock and a chemical catalysts. This method aims to optimize the feedstock-to-fuel conversion process in order to improve fuel yield and reduce production costs. The patent focuses on enhancing the efficiency and effectiveness of the SAF production process, ensuring that the fuels can be seamlessly integrated into existing aviation infrastructure and used in current aircraft engines with minimal modifications. The ultimate goal is to provide a commercially viable and environmentally friendly alternative to conventional jet fuels, reducing the aviation industry's carbon footprint and dependency on fossil fuels.

The invention described in WO2022171643A1 from Topsoe involves an innovative method for producing SAF. This method focuses on using bio-based feedstock, such as vegetable oil and animal fat, and employs advanced chemical catalysts to optimize the conversion process. The goal is to enhance the efficiency of the feedstock-to-fuel conversion, resulting in a higher fuel yields and reduced production costs.

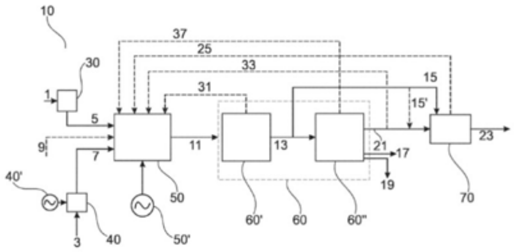
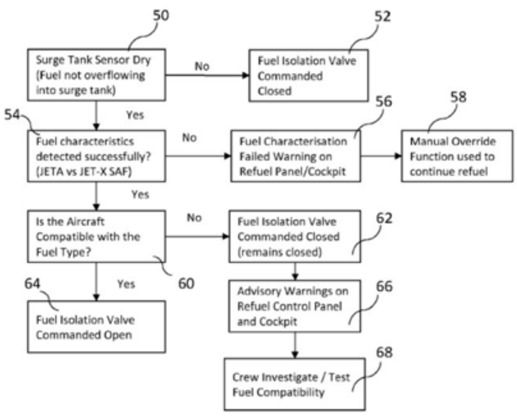


Fig. 1

Source: WO2022171643A1.

Additionally, SAFs produced using this method are designed to be compatible with existing aviation infrastructure and engines, requiring only minimal adjustments to fuel delivery systems. This approach aims to provide a commercially viable and environmentally-friendly alternative to conventional jet fuel, thereby reducing the aviation industry's carbon footprint and reliance on fossil fuels.

The invention from Airbus described in patent EP4382431A1 involves the development of a novel method for producing SAFs from bio-based feedstock, such as vegetable oils and animal fats. This method leverages advanced chemical catalysts in order to enhance the efficiency of the conversion process, resulting in a higher fuel yield and reduced production costs. SAFs produced through this method are designed to be compatible with existing aviation infrastructure and engines, requiring only minor adjustments to fuel delivery systems.



Source: EP4382431A1

This innovative approach aims to provide a commercially viable and environmentally friendly alternative to conventional jet fuel, thereby reducing the aviation industry's carbon footprint and dependence on fossil fuel. The process outlined in the patent emphasizes optimizing the feedstock-to-fuel conversion to ensure high efficiency and sustainability.

The adoption of SAF in air transportation is influenced by evolving regulations and standards aimed at promoting sustainability and reducing environmental impacts. Organizations like ICAO and IATA are working on developing standards specific to SAF, addressing production processes, fuel quality and sustainability criteria to assure their reliable integration into commercial aviation.[14] [15]

14 ICAO (2017). Sustainable Aviation Fuels Guide. International Civil Aviation Organization. Available at: www.icao.int/environmental-protection/knowledge-sharing/Docs/Sustainable%20Aviation%20Fuels%20Guide_vf.pdf.
15 IATA (2024). IATA SAF Registry. International Air Transport Association. Available at: www.iata.org/en/pressroom/2024-releases/2024-06-02-02.

Emerging technology in detail: urban air mobility

Urban air taxis represent a significant advancement in urban air mobility (UAM), providing a new mode of transportation aims at alleviating urban congestion and reducing travel times in densely populated areas. Urban air taxis, often referred to as eVTOLs (electric vertical takeoff and landing aircraft), are designed to operate within urban environments, offering an efficient and sustainable alternative to traditional ground transportation. The adoption of urban air taxis is crucial for transforming urban transportation, reducing emissions and enhancing the overall efficiency of city travel. [1]

Currently, demand for urban air taxis is growing, with various companies and research institutions actively developing and testing eVTOLs. However, significant challenges remain in terms of infrastructure development, regulatory frameworks and public acceptance. Manufacturers and operators are increasingly conducting test flights and demonstrations to showcase the feasibility and benefits of urban air taxis. Planned production capacities are expected to ramp up over the next decade, but widespread adoption will require substantial investment and supportive policies.

There are several types of urban air taxis currently under development, each with unique characteristics and technologies (Figure C62). [2]

Vectored thrust: Such powered lift eVTOL aircraft utilize all of their lift/thrust units for both vertical lift and cruising. This is achieved by rotating (vectoring) the resultant thrust points against the direction of motion. Such thrust vectoring can be accomplished in several ways: by rotating the entire wing-propulsion assembly (tilt wing), by rotating the lift/thrust unit itself (tilt fan for ducted fans and tilt prop for propellers), or by rotating the entire aircraft frame pivoted about the fuselage (tilt body or tilt frame). An example of this configuration is the Lilium jet, which utilizes ducted and vectored thrust through distributed electric propulsion (DEP).

Wingless: This configuration is relatively simple and can be very efficient during vertical take-off, landing and hovering, because of low disc-loading. However, without wings, multicopters lack cruise efficiency, which limits their application to urban air mobility markets only. An example of this category is the Volocopter VC2X, which runs on nine independent batteries, powering 18 electric motor-driven variable-speed/fixed-pitch propellers. The resultant redundancy ensures stability in the event of a component failure.

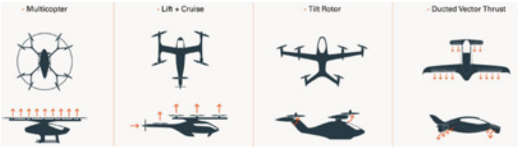
Lift plus cruise: Such aircraft combine the capabilities of a multicopter for vertical takeoff and landing with those of a standard aircraft for cruising in flight. This integration enables the aircraft to achieve both efficient vertical takeoff and landing as well as efficient cruise performance. To optimize the range of such concepts, the propellers required for VTOL are designed with fewer blades and shorter chords, so as to minimize drag when cruising in flight. However, the small size of the propellers used for VTOL operations presents a notable challenge in terms of the noise emissions, mainly resulting from and increased blade tip speeds. The Kitty Hawk Cora is an example of this configuration.

1 Rajendran, S. and S. Srinivas (2020). Air taxi service for urban mobility: A critical review of recent developments, future challenges, and opportunities. Transportation research part E: Logistics and transportation review, 143, 102090.

2 Chahba, S., R. Sehab, C. Morel, G. Krebs and A. Akrad (2023). Fast sizing methodology and assessment of energy storage configuration on the flight time of a multirotor aerial vehicle. Aerospace, 10(5), 425.

Tilt rotor: This configuration involves either the wing and propellers or the propellers alone (tilting). This enables the propeller axis to rotate by 90 degrees as the aircraft transitions from hover to forward flight. This architecture generally allows for the design of a more optimized propeller compared to a lift and cruise aircraft configuration. However, it comes with the trade-off of higher technical complexity and larger overall size and weight owing to the inclusion of tilt and variable pitch mechanisms. Joby S4, developed by Joby Aviation, is an example of this category of aircraft and is expected to be commercialized by 2024.

Figure C62 eVTOL propulsion configuration



Source Chahba et al., 2023.

[3]The core benefits of urban air mobility include reduced travel times, decreased urban congestion and lower emissions. Urban air taxis can significantly reduce travel times by bypassing ground traffic and utilizing direct flight paths.[4] Additionally, eVTOLs contribute to decreased urban congestion by providing an alternative to traditional road vehicles, thereby reducing the number of cars on the road. Urban air taxis are typically powered by electric or hybrid-electric propulsion systems, resulting in lower emissions compared to conventional internal combustion engine vehicles. Furthermore, urban air taxis offer increased connectivity and accessibility, especially in areas with limited ground transportation options, enhancing the overall urban transportation network.[5]

The adoption of urban air mobility can also lead to substantial economic benefits. According to Deloitte, the implementation of air taxi services can create new job opportunities in vehicle maintenance, operations management and pilot training. Additionally, urban air taxis can stimulate technological advancements in battery technology, autonomous flight systems and air traffic management.[6]

Despite their advantages, urban air mobility has several current limitations. The development and certification of eVTOLs is complex and requires significant investment. Additionally, there are technical challenges related to battery technology, flight safety and noise reduction. Ensuring the reliability and safety of urban air taxis in various operating conditions is critical.[7] Urban air taxis currently have limited range and payload capacity compared to traditional aircraft, primarily due to battery constraints. The infrastructure required for urban air taxi operations, such as vertiports and charging stations, is still in the early stages of development. Regulatory frameworks and air traffic management systems need to be established to support the safe integration of urban air taxis into the existing airspace.[8]

Rajendran and Srinivas highlight that one of the key challenges is the development of efficient ride-matching algorithms and pricing strategies to optimize the use of air taxi services. Additionally, vehicle maintenance scheduling and pilot training and recruitment are critical areas that need to be addressed to ensure the scalability and reliability of urban air mobility.[9]

3 Chahba, S., R. Sehab, C. Morel, G. Krebs and A. Akrad (2023). Fast sizing methodology and assessment of energy storage configuration on the flight time of a multirotor aerial vehicle. Aerospace, 10(5), 425.
4 NASA (2020). Urban Air Mobility Operational Concept (OpsCon) Passenger-Carrying Operations. National Aeronautics and Space Administration. Available at: https://ntrs.nasa.gov/api/citations/20205001587/downloads/UAM%20Passenger-carrying%20OpsCon%20-%20v14%20GP%20accept.pdf.
5 Rajendran, S. and S. Srinivas (2020). Air taxi service for urban mobility: A critical review of recent developments, future challenges, and opportunities. Transportation research part E: Logistics and transportation review, 143, 102090.
6 Deloitte (2021). Advanced air mobility: Can the United States afford to lose the race? Deloitte Insights. Available at: www2.deloitte.com/us/en/insights/industry/aerospace-defense/advanced-air-mobility.html.
7 Torens, C., A. Volkert, D. Becker, D. Gerbeth, L. Schalk, O. Garcia Crespillo et al. (2021). HorizonUAM: Safety and security considerations for urban air mobility. In AIAA Aviation 2021 Forum, 3199.
8 Decker, C. and P. Chiambaretto (2022). Economic policy choices and trade-offs for Unmanned aircraft systems Traffic Management (UTM): Insights from Europe and the United States. Transportation research part A: policy and practice, 157, 40–58.
9 Rajendran, S. and S. Srinivas (2020). Air taxi service for urban mobility: A critical review of recent developments, future challenges, and opportunities. Transportation research part E: Logistics and transportation review, 143, 102090.

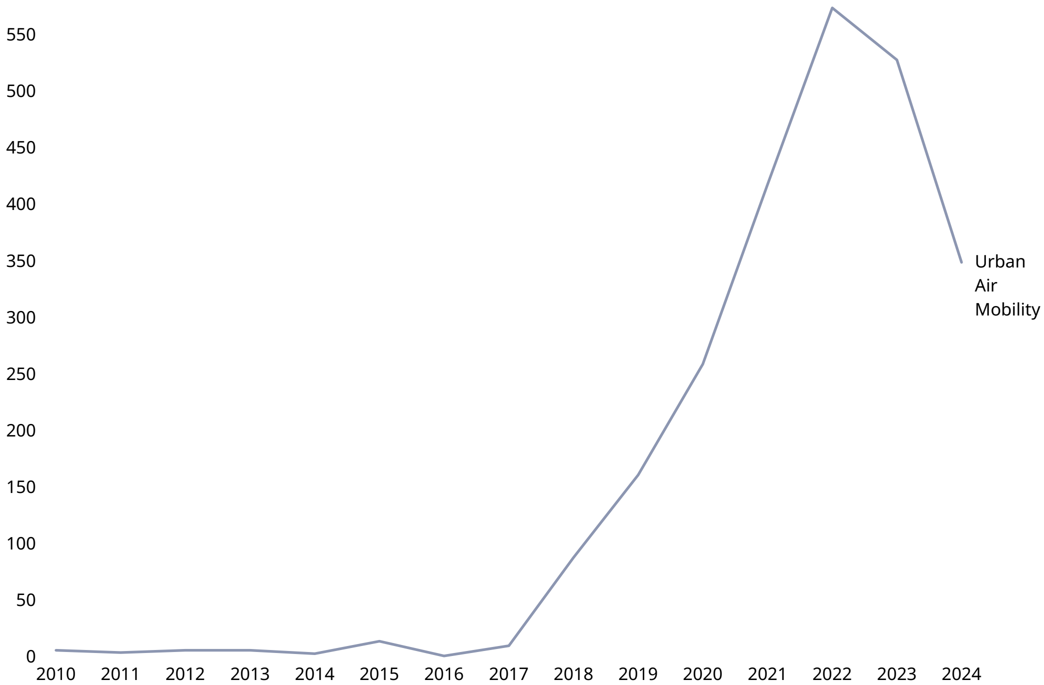
Urban air mobility: scientific publications

The scientific community has shown an increasing interest in urban air taxis, as evidenced by the growing number of publications on the topic. Research focuses on improving eVTOL technology, assessing environmental impacts and enhancing the safety and efficiency of urban air mobility (Rajendran and Srinivas, 2020).[10]

Figures C63–C65 illustrate the trends in scientific publications related to urban air taxis from 2004 to 2024 and the leading countries contributing to this research. Figure C63 shows there has been a steady increase in publications, with a significant surge starting around 2017. This trend indicates a growing interest in urban air taxis and their potential to transform urban transportation.

A steady increase in publications is seen, with a significant surge starting around 2017, indicating a growing interest in urban air taxis and their potential to transform urban transportation

Figure C63 Development of global scientific publications related to urban air mobility, 2004–2024



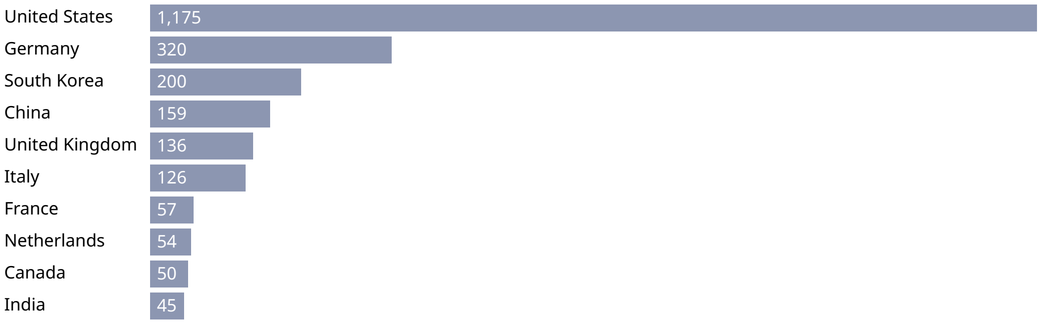
Source: WIPO, based on publication data from EconSight/Scopus, October 2024.

Figure C64 highlights the number of scientific publications related to urban air mobility by country. The United States leads with a significant number of publications, followed by Germany, the Republic of Korea, China, the United Kingdom, Italy, France, the the Kingdom of the Netherlands, Canada and India. This distribution reflects a global interest and investment into developing urban air mobility solutions.

10 Rajendran, S. and S. Srinivas (2020). Air taxi service for urban mobility: A critical review of recent developments, future challenges, and opportunities. Transportation research part E: Logistics and transportation review, 143, 102090.

The United States leads with a significant number of publications, followed by Germany and South Korea

Figure C64 Origin countries for scientific publications related to urban air mobility



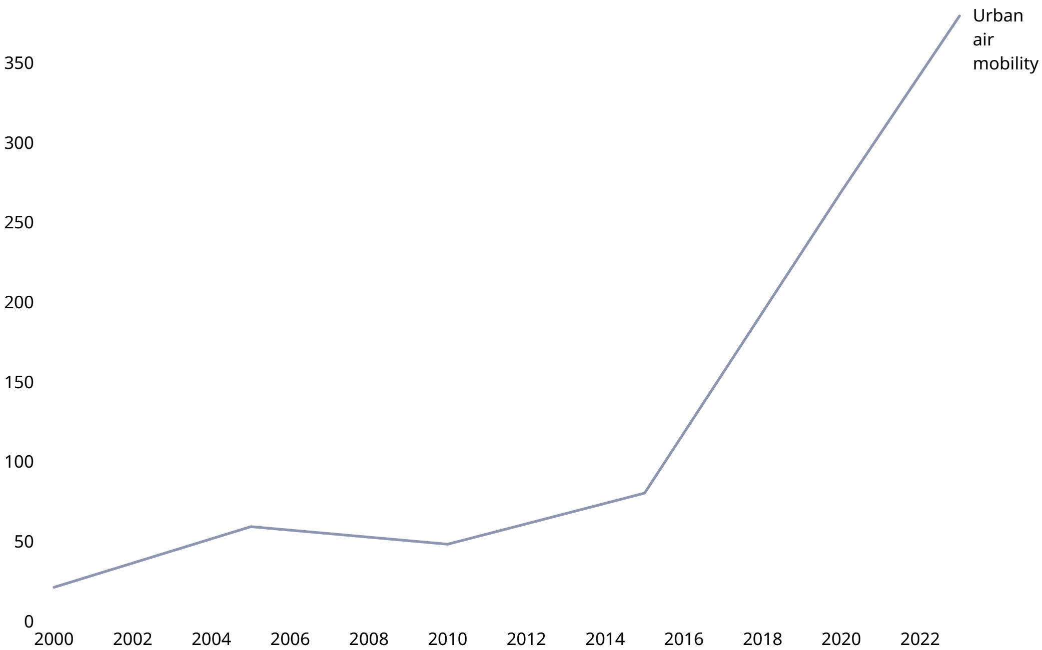
Source: WIPO, based on publication data from EconSight/Scopus, October 2024.

Urban air mobility: patent data

Patenting activity in the field of urban air mobility has picked up speed significantly over the last 10 years. The number of global patent family publications has jumped from 67 in 2014 to 379 in 2023 (Figure C65).

Urban air mobility patenting has surged, with global publications rising from 67 in 2014 to 379 in 2023

Figure C65 Development of global patent family publications related to urban air mobility, 2000–2023

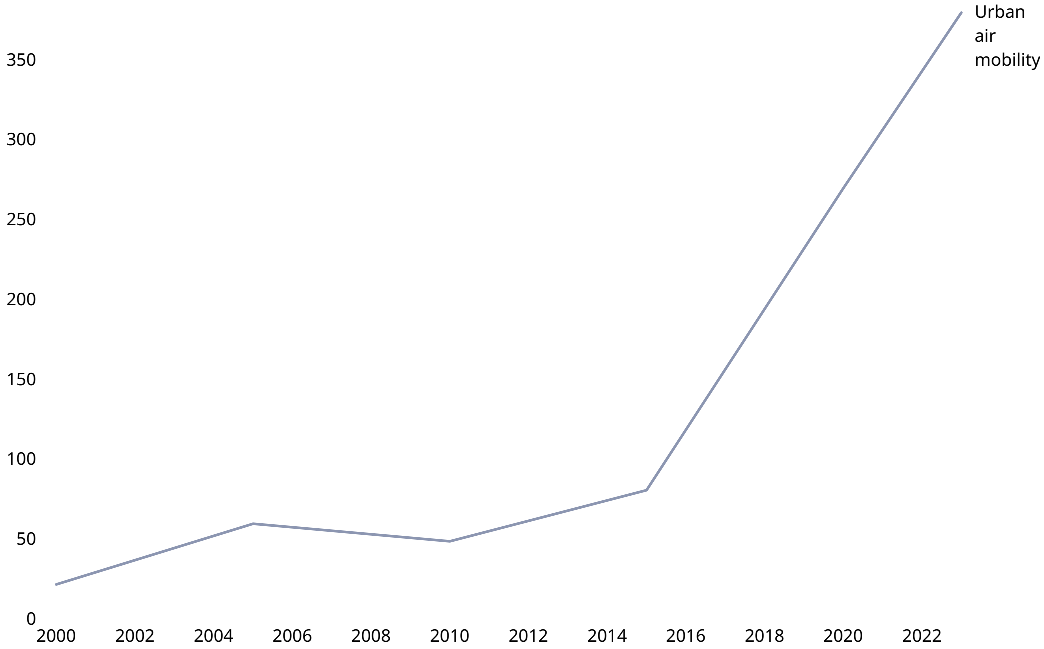


Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

At a country level, most patent family publications were developed in the United States (988) (Figure C66). Textron, Beta Technologies and Boeing are key US research players that are developing eVTOLs. China, the Republic of Korea and Japan and Germany are other important research locations.

The US leads in urban air mobility patents (988), with key players like Textron, Beta Technologies and Boeing

Figure C66 Patent family publications related to urban air mobility, 2000–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Urban air mobility: patent examples

Recent developments from Lilium (EP3998191A1) include a vertical takeoff and landing (VTOL) passenger aircraft, emphasizing easy luggage access and energy efficiency. This VTOL aircraft combines helicopter-like capabilities for limited space takeoffs and landings with the high-speed and efficient cruising of conventional aircraft, aiming to reduce energy consumption, especially in electrically-powered(eVTOL) models. It includes a fuselage with a passenger cabin and a rear-accessible cargo bay, featuring an upward-opening door for efficient luggage loading without hindering passenger movement. The cargo bay is optimally positioned and sized to balance weight distribution and minimize aerodynamic drag. This design supports urban air taxi services, offering convenient regional mobility with sufficient luggage capacity and rapid access.

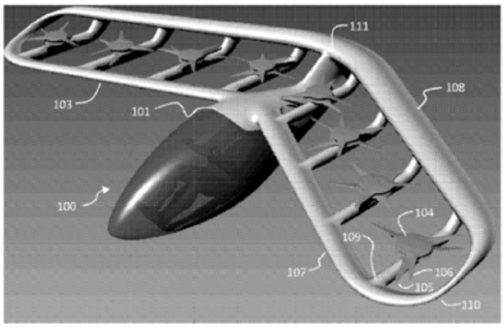
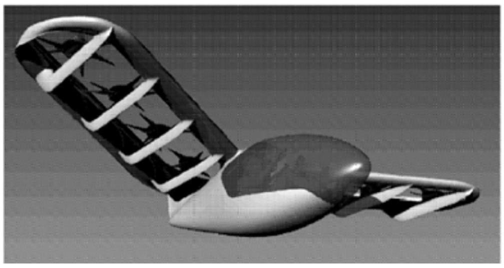
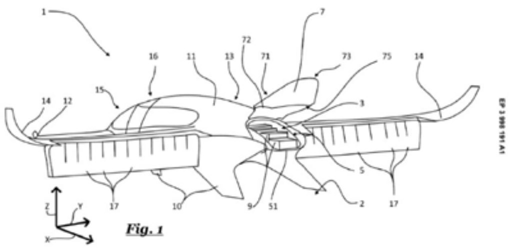


FIG. 1A



Source: EP3535185A1

Another recent development from Joby Aviation (EP3535185A1) describes a VTOL aircraft that utilizes fixed rotors both for vertical takeoff and landing and for forward flight operations. The key feature of this aircraft is the use of a "synthetic wing" formed by an array of rotors. These rotors are positioned along the span of the wing to achieve high a span efficiency and an even lift distribution. The synthetic wing also includes narrow front and rear airfoils that provide additional structural support and lift during forward flight. The rotors are designed to tilt forward during horizontal flight, thus providing forward propulsion. This design aims to simulate the aerodynamic benefits of traditional aircraft wings, including even lift and controlled downwash, with concentrated vorticity at the wingtips.



Source: EP3998191A1

The first patent is geared toward creating a practical and efficient VTOL aircraft for urban air taxi services, with a strong emphasis on passenger convenience and efficient luggage handling. The second invention focuses on aerodynamic innovation, using fixed rotors to form a synthetic wing that provides efficient lift and propulsion, optimizing the aircraft's aerodynamic performance. While both designs address the need for efficient VTOL operations, their primary focus and structural approach differs significantly.

The adoption of urban air mobility is influenced by evolving regulations and standards aimed at promoting safety, sustainability and efficiency. Organizations like the Federal Aviation Administration (FAA) and the European Union Aviation Safety Agency (EASA) are working on developing standards specific to eVTOLs, addressing certification processes, operational guidelines and air traffic management systems to ensure their reliable integration into urban airspace. [11] Regulatory frameworks will need to evolve to support the unique operational requirements of urban air mobility, including airspace integration, flight crew licensing and maintenance standards. [12]

11 FAA (2024). FAA Statement on eVTOL Aircraft Certification. Federal Aviation Administration. Available at: www.faa.gov/newsroom/faa-statement-evtol-aircraft-certification.

12 Rajendran, S. and S. Srinivas (2020).Air taxi service for urban mobility: A critical review of recent developments, future challenges, and opportunities. Transportation research part E: Logistics and transportation review, 143, 102090.

Appendix: methodology for patent analysis

Data collection, patent counting

- Simple published patent families are counted as a proxy for individual inventions in the report. A simple patent family is a set of patents in various countries in relation to a single invention. The technical content covered is considered to be identical. All patent documents have the same priority date or combination of priority dates. The first publication by a member of a patent family counts as the publication year.
- Most analysis in the report refers to numbers of patent families. Only published patent families have been studied.
- Patent families generally include only patents and not utility models, without assessing their legal status.
- The origin of the inventor (inventor's location or residence) is used as a proxy for the source of innovations. For patents with multiple inventors, we count the different locations listed and count the location for multiple inventors of the same origin once.

Utility models have been excluded from the patent analysis in this report, because the regional differences and lower inventive threshold for utility models can affect the accuracy and relevance of the analysis.[1] Utility models are not available in every country or region, therefore their inclusion can create inconsistencies in global studies, such as this report, for which comparability across countries and between regions is essential. The requirements for obtaining a utility model are also less stringent than those for a patent and they often cover incremental improvements rather than significant innovations, so including them can dilute the focus on more substantial technological advancements.

Patent indicators

Patent application

To obtain a patent, an application must be filed in the appropriate IP office with all the necessary documents and fees. The IP office will conduct an examination to decide whether to grant or reject the application. Patent applications are generally published 18 months after the earliest priority date of the application. Prior to that publication, the application remains confidential.

Patent classification

Patent classification is a system for examiners of IP offices or other people to code documents, such as published patent applications, according to the technical features of their content. The International Patent Classification (IPC) is agreed internationally. The European Patent Office (EPO) and United States Patent and Trademark Office (USPTO) launched a joint project to create the Cooperative Patent Classification (CPC) in order to harmonize the patent classifications systems between the two offices.

1 See, Utility models, available at: www.wipo.int/web/patents/topics/utility_models.

Patent applicant/owner

Patents are filed by an applicant, which can be an organization or a natural person. Applicants are not inventors, even if sometimes they are similar. The applicant is in most jurisdictions and in most cases published with the patent and remains always the applicant. The applicant is not automatically the owner of a patent at a given time, even if that is often the case. Patents can be transferred or sold, or the applicant itself can be sold as a company in a merger or takeover. Therefore the “owner” of a patent might change over time and is not always published. For proper analysis, to consolidate incorrect spelling and to include merger and acquisition information in the analysis, the report used the ultimate owner concept in the IFI Claims global patent database. The most probable entity was then named as owner.

Patent family

A patent family is a collection of patent applications covering the same or similar technical content and all sharing one or more priority documents. Families are used to count inventions and not several patents corresponding to the same subject matter and filed in different jurisdictions. There are several definitions of patent families, including simple and extended patent families, depending on the number of priority documents shared (ranging from one to all priority documents). Patent family members are the individual patents filed in those jurisdictions where a patent applicant is seeking patent protection (e.g., WIPO, EPO) and all publications in relation to these. In the present study, we counted simple patent families (using a representative patent family member for each patent family), unless otherwise specified.

Granted patent

Once examined by the IP office, an application becomes a granted patent or is rejected. If granted, the patent gives his owner a temporary right for a limited time period (normally 20 years) to prevent unauthorized use of the technology outlined in the patent. Procedure for granting patents varies widely between locations according to national laws and international agreements. Note that in the same patent family, an application can be granted in one location and rejected in another.

Inventor country/location

The origin of the inventor (inventor’s location or residence) is used as a proxy for the source of innovation. For patents with multiple inventors, we counted the different locations listed and counted the location for multiple inventors of the same origin once. If no inventor address was available, the patent priority country/location was used as a proxy for the source of innovation.

Priority country/location

The first location in which a particular invention has a patent application filed, also known as the office of first filing.

Filing country/location

The filing country/location is the legal jurisdiction in which a member of a patent family filed a patent application to seek patent protection.

PCT (WO)

The Patent Cooperation Treaty (PCT) is an international patent law treaty concluded in 1970, administered by the World Intellectual Property Organization (WIPO), between more than 140 Paris Convention locations. The PCT makes it possible to seek patent protection for an invention simultaneously in each of a large number of locations by filing a single “international” patent application instead of filing several separate national or regional patent applications. The granting of patents remains under the control of the national or regional patent offices, which is referred to as the “national phase.”

European patent (EP)

A European patent can be obtained for all the European Patent Convention (EPC) locations by filing a single application at the European Patent Office (EPO). European patents granted by the EPO have the same legal rights and are subject to the same conditions as national patents (granted by the national patent office). A granted European patent is a “bundle” of national patents, which must be validated at the national patent office to be effective in member locations. The validation process could include submission of a translation of the specification, payment of fees and other formalities at the national patent office. Once a European patent is granted, competence is transferred to the national patent offices. Other regional patents or procedures also exist: the Eurasian patent (EA), ARIPO patent (AP) for English-speaking Africa and OAPI patent (OA) for French-speaking Africa.

Relative Specialization Index

The Relative Specialization Index (RSI) compares the published patenting activity in two or more locations within the same technology area. RSI is a measure of a location’s share of patent families in a particular field of technology as a fraction of that location’s share of patent families in all fields of technology. It accounts for the fact that some locations file more patent applications than others in all fields of technology.

In other words, RSI has the advantage of providing a comparison of two locations’ patenting activity in a technology relative to those locations’ overall patenting activity. The effect of this is to highlight locations which have a greater specialism of the technology area studied than expected from their overall level of patenting, and which might otherwise appear further down in the top inventor location lists, often unnoticed. A positive RSI value indicates that a location has a higher specialization in this field than would be expected, whilst a negative value indicates a lower specialization than expected for that location.

The Relative Specialization Index (RSI) is calculated as follows:

$$RSI = \frac{X - 1}{X + 1}$$

where X is given by,

$$X_{c,t} = \frac{n_{c,t}/N_c}{N_t/N}$$

and

$n_{c,t}$ is the number of published patent families in country c for technology t,

$N_c = \sum_t n_{c,t}$ is the number of published patent families in country c in all technologies,

$N_t = \sum_c n_{c,t}$ is the number of published patent families in technology t in all countries, and

$N = \sum_c \sum_t n_{c,t}$ is the number of published patent families in all technologies and all countries.

Patent searches

Full details of the patent search strategies used to define the technology areas analyzed in this report can be accessed and downloaded from the WIPO Technology Trends webpages. [2]

2 See, WIPO Technology Trends, available at: www.wipo.int/web/technology-trends.

This technical annex to the *WIPO Technology Trends* Report on the Future of Transportation provides an in-depth analysis of air transportation, focusing on global patenting trends that reveal key technological advancements within the aviation industry.

WIPO
WORLD
INTELLECTUAL PROPERTY
ORGANIZATION