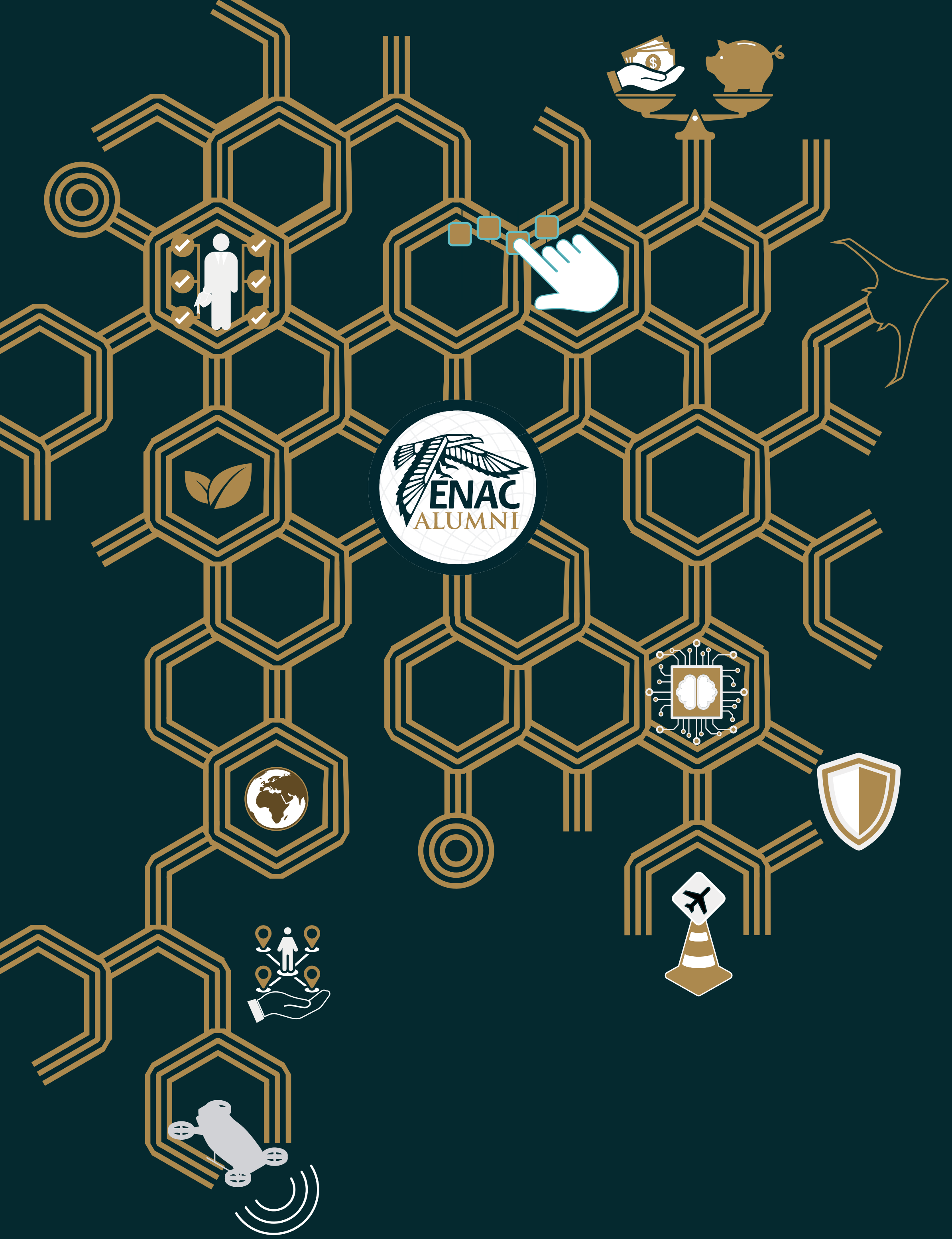


THE FUTURE OF AIRPORTS:

A VISION OF 2040 AND 2070

ENAC Alumni, 7 Avenue Edouard Belin,
CS 54005, 31400 Toulouse Cedex 4, France

ISBN: 978-2-9596441-0-8

SUGGESTED CITATION:

Le Bris, G., & Nguyen, L.-G. (2024). The Future of Airports: A Vision of 2040 and 2070. (M. Houalla, et al.). Toulouse: ENAC Alumni.

CITATION SUGGÉRÉE :

LE BRIS, Gaël et Loup-Giang NGUYEN. The Future of Airports: A Vision of 2040 and 2070 (L'aéroport du futur : une vision de 2040 et 2070). Avec la collaboration de Marc HOUALLA et al. Toulouse : ENAC Alumni, 2024.

TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

RESEARCH TEAM

Gaël Le Bris, CM, ENV SP, PE
WSP, Raleigh, NC, USA (Principal Investigator)

Loup-Giang Nguyen
WSP, Raleigh, NC, USA (Deputy Project Manager)

GLOBAL PANEL MEMBERS

Eduardo H. Bernardi
Formerly with Ministério da Infraestrutura, Brasília - DF, Brazil

Andy Brooker-Tormey
Air Arabia, Dubai, UAE

Philippe Fonta
SCRUM-Consult, Geneva, Switzerland

Matthieu Gualino
LOGYx, Toulouse, France

Ernie Heymsfield
University of Arkansas, Fayetteville, AR, USA

Marc Houalla
Direction Générale de l'Aviation Civile (SEAC-PF), Papeete, France

Marc Huault
Master Horizon, Montlaur, France

Maurice Jenkins
Miami-Dade Aviation Department, Miami, FL, USA

Pierre Jouniaux
Safety Line, Paris, France

Magali Kintzler
Direction Générale de l'Aviation Civile (DSNA), Roissy-en-France, France

Philippe Laborie
Groupe ADP, Roissy-en-France, France

Nicolas Lamballe
ENAC, Toulouse, France

Ferran B. Lazaro
Quside Technologies S.L., Barcelona, Spain

Eugene Leeman
ACI Europe, Brussels, Belgium

Guy Marguet
Genève Aéroport, Geneva, Switzerland

Thomas Pétrelle
TP Consulting, Orly, France

Arlyn Purcell
Formerly with Port of Seattle, Seattle, WA, USA

Michel Ricaud
Groupe ADP, Orly, France

Olivier Sciara
UAF&FA, Paris, France

REGIONAL FOCUS GROUP PARTICIPANTS

Glawdys Flora Akete Oyono
Ministère des Transports, Yaoundé, Cameroon

Lionel Bernard-Peyre
Thales, Toulouse, France

Raymond Bisse Bell
Cameroon Civil Aviation Authority, Yaoundé, Cameroon

Pierre Bougeard
United Airlines, San Francisco, CA, USA

Sally Blackwell
S N Blackwell, Redhill, UK

Thomas Budd
Cranfield university, Milton Keynes, UK

Matthew Butters
British Aviation Group, London, UK

Patty Clark
Patty Clark Aviation Advisors, New York City, NY, USA

Luis Delgado
University of Westminster, London, UK

Yonglian "Liana" Ding
Boeing, Mukilteo, WA, USA

Léopoldine Essimi
Ministère des Transports, Yaoundé, Cameroon

Michael Gernant
Port Authority of New York and New Jersey, NY, USA

Clint Harper
Harper 4D Solutions, Ogden, UT, USA

Serge Hodonou
Ecole Africaine de Météorologie et d'Aviation Civile, Niamey, Niger

Stéphane Frank Kamga
Airbus Protect, Blagnac, France

Moses Koyabe
MK Consulting, Grand Rapids, MI, USA

Ferdinand Koyema
ASECNA RCA, Niamey, Niger

Jim Krieger
Worldwide Aviation Solutions, Wauconda, IL, USA

Milad Larkem
MarketAxess, London, UK

Martin Lavrilloux
Steer, London, UK

Etienne Law de Lauriston
Groupe ADP, Roissy-en-France, France

Paul Le Blond
Formerly with Loughborough University, Loughborough, UK

François Le Doze
Eurostar, London, UK

Pierre-Yves Leseigneur
Alstom Group, London, UK

François Libre
Manchester Airports Group, Manchester, UK

Syed Mehdi
Metropolitan Nashville Airport Authority, Nashville, TN, USA

Guillaume Mortagne
SITA, London, UK

Romuald Touembou Ngueyap
ASECNA, Douala, Cameroon

Benoit H. Noukpo
Ceiba Aeropuertos, Baney, Equatorial Guinea

André Nzuzi
Régie des voies aériennes, Kinshasa, Democratic Republic of the Congo

Alexandra Ott
Mott MacDonald, Nice, France

Daniel Parker-Klein
The Chartered Institute of Logistics & Transport, London, UK

Julie Philippon
CH2M, Boise, ID, USA

Thomas S. "Max" Platts
Wisconsin Department of Transportation, Madison, MI, USA

Neil Pritchard
Heathrow Airport, Southend-on-Sea, UK

Bettina Rigg
British Aviation Group, London, UK

Clémence Routaboul
Steer, London, UK

Maxime Valencik
Blue Origin, Cape Canaveral, FL, USA

Antoine Vergoz
ICF, London, UK

Cécile Vernhes
Direction Générale de l'Aviation Civile (DSNA), Bordeaux, France

Ian Villa
Whisper Aero, Nashville, TN, USA

Liliane Zoungarani
ASECNA, Bangui, Central African Republic

Vaneck Ntantame
Ministère des Transports, Yaoundé, Cameroon

ABOUT THE PROJECT

The Future of Airports was initiated in March 2019 shortly after the creation of the Airport Think Tank of ENAC Alumni. This research project was developed to investigate the numerous changes impacting aviation facilities, identifying their drivers and influencers and fostering the conversation on how to mitigate emerging threats and identify future opportunities. Each decade of modern aviation history had its critical future airport issue that mobilized decision-makers and experts alike. Capacity and delay were the major concerns of the late 1980s. Accommodating the New Large Aircraft was the moonshot of the 1990s. In the early 2000s, the devastation of the September 11 attacks brought attention to the immediate security threats from terrorism.

Today is different. There is no one single issue but rather a multitude of significant challenges that need to be addressed. The unique marker of our decade is that everything we know about airport domains and activities is evolving. This movement is unprecedented, and the coming years will redefine aviation as a whole. We need to learn, prepare, and adapt, but the complexity and urgency require a holistic strategy. It is vital to consider these evolutions with a multidisciplinary approach to understand the timelines and implications for all the stakeholders. The Future of Airports was developed to provide a vehicle for such understanding, and to create a forum for the aviation community to learn about these issues and think about the future together.

During the first 12 months after inception, the research team conducted initial investigations and brought together a global panel of aviation thought leaders. These leaders convened for virtual workshops, during which, 11 topics were discussed one by one. A first version of the report was published in April 2020. The second phase of the project started after the release of the first findings. Regional focus groups were organized in Central Africa, the United Kingdom, and the United States to review the results of the global analysis and discuss how they apply to these parts of the world. Region-specific issues were also explored. In parallel, the findings gathered so far were presented to various industry organizations and research institutions. These discussions, held between 2020 and 2022, brought new ideas and perspectives. The third and final phase of the effort consisted of complementary studies executed in 2023 and 2024.

During the course of this project, the world has changed. The COVID-19 pandemic brought air transportation to a near standstill. Interstate conflicts have wreaked havoc across entire regions and shaken route networks and the supply chain. Climate change is striking communities across the globe. These events and more have deeply impacted civil aviation. Interestingly, the foundations of the 2020 version of this study have shown a strong resilience to these crises.

This document is the result of that five-year process and it is the second version of the research report on the future of airports at the 20- and 50-year horizons. It should be read as a guide to understand the challenges and opportunities ahead. It features tools and technical contents documenting trends and emerging issues. Finally, it contains extensive references to provide decision-makers and practitioners with further reading options. The new version of the report includes new findings and additional conversations, delving into subjects that were not presented with enough thoroughness previously.

FOREWORD

In February 2019, ENAC Alumni–the alumni association of the National University of Civil Aviation (ENAC)–organized a day of discussion and education on the current and future challenges in air transportation: The State of the Air ("Les Etats de l'Air"). This event, held at the headquarter of the French General Directorate for Civil Aviation (DGAC), was part of a broader effort to fulfill some of our primary missions toward our 24,000 members: to maintain their knowledge up to date, to provide them platforms where to express and exchange ideas, and to promote excellence in aviation & space.

In addition to master classes on Airports, Aircraft and Systems, Design & Certification, Airline Operations, Air Traffic Management, Aircraft Maintenance, Pilots & Flight Operations, Safety & Compliance, and Entrepreneurship, the State of the Air featured a series of roundtables bringing together key leaders of the industry in the sectors of air transportation, tourism and general aviation who presented their vision of the future.

Following the large success of the State of the Air, and considering the dedication and expertise of our alumni, it has been decided to take the momentum and invite our think tanks to launch projects on the future of aviation. These think tanks reflect the diversity and excellence of our alumni community: air traffic management, airline operations, airports, digital innovation, and sustainable development.

The Airport Think Tank chaired by Gaël Le Bris is one of the most active of our research groups. The Future of Airports is an important study that brings a significant value added to help us foresee future challenges and prepare our industry for the changes to come. The participants of The Future of Airports have provided remarkable work. The output of the working sessions and the research findings are being released as white papers and other practice-ready materials that will be shared and brought to decision makers and leaders of both the public and private sectors worldwide. I am confident that the outcome of this Think Tank will be a huge move forward for the promotion and recognition of the ENAC Alumni•

MARC HOUALLA

(IENAC 82 / IAC 89)

PRESIDENT OF ENAC ALUMNI

INTRODUCTION

The Future of Airports: A Vision of 2040 and 2070 is an initiative of the Airport Think Tank of ENAC Alumni. The research effort was conducted between 2019 and 2024 to investigate the long-term future of aviation facilities. The project has involved aviation thought leaders from diverse backgrounds and affiliations. Together, thought leaders and the research team examined the ongoing trends, emerging innovations, and possible disruptions. We considered their potential benefits and challenges for air transportation, and we identified the needs in research, education, and policies to prepare and adapt proactively for these changes.

The future of airports cannot be envisioned without considering the future of our societies. At the 2040 and 2070 horizons of our study, the world population will be bigger than ever. Overall, we will be wealthier and more educated and have a longer life expectancy. However, populations will face increased impacts from climate change that will strain resources and communities, and people will demand more equity and shared prosperity. How can aviation address these new paradigms and continue to provide its unique mobility to the world under changing social expectations?

First and foremost, we must never forget that safety always comes first in our line of business. As we make air transportation increasingly automated and connected, and as we integrate new users and technologies into aviation systems, we must remember that our top priority must be to safeguard life, health, and property, and to promote the public welfare.

Human-induced climate change is the most formidable threat to our civilization. Transportation must become net zero if we want to sustain the development of our societies without degrading our well-being and endangering public health at a horizon increasingly visible. Our industry will continue leading the way in this domain.

As aviation professionals, it is our mission to connect people together and move freight around the world. Aviation must remain a place of opportunities, and it should “create and preserve friendship and understanding among the nations and peoples of the world,” as stated in the Convention on International Civil Aviation.

Being future-ready will help us shape our destiny for the benefit of humanity. By 2040 and 2070, groundbreaking technological innovations, scientific discoveries, and social and political changes that we cannot anticipate today will deeply influence our world. But if we make ethical and sustainable decisions, we can make a difference for the better. Aviator and writer Antoine de Saint-Exupéry said that when it comes to the future, “it is not about foreseeing it, but about making it possible.” Let us make a bright aviation future possible together.

GAËL LE BRIS

(IENAC 07)

VICE PRESIDENT OF ENAC ALUMNI & CHAIR OF THE AIRPORT THINK TANK

CHAPTER 1

THE WORLD IN 2040 AND 2070

A MORE POPULATED WORLD: ADDING THREE TO SIX BILLION HUMANS BY 2070

Today, the world population is more than eight billion people. There will be more than nine billion humans in 2040, and more than 10 billion in 2070.[a] While the demography of the more developed regions will be nearly stagnant (and perhaps already shrinking by the mid-century), most of the worldwide population growth will occur in Asia and Africa. The latter will observe the highest growth rates over the next 20 to 50 years. The African continent will account for 31% of all humankind by 2070 (Fig. 1). Nigeria, currently with the world's sixth largest population, is projected to surpass the United States and become the third most populated country before 2050.[1] These trends can dramatically modify the long-term balance of power and the aviation demand across the world.

While the global population will continue growing over the coming decades, living conditions in the emerging and underdeveloped regions will improve. Half of humanity is now considered to be part of the middle class, which is defined as the households spending between at least $12 per day per person on a 2017 purchasing power parity basis.[2,3] There is a strong correlation between wealth and air travel.[4,5] The passenger demand continues to show its long-term resilience facing crises. Following a sharp decline during the COVID-19 pandemic, passenger demand is set to surpass the pre-pandemic levels in 2024 and to keep growing beyond 2040.[6,7,8] To address this growth, new airports and route networks are needed. This includes both regional airports and large hubs such as Istanbul Airport and Beijing Daxing International Airport. They both opened in 2019 and each ultimately intends to accommodate 100 to 200 million passengers per year. In 2020, the Civil Aviation Administration of China announced plans to build 216 airports by 2035.[9] In 2023, India kicked off a $12 billion program to expand its airport system from 148 to 220 facilities by 2025.[10] The same year, Brazil announced its commitment to allocate R$ four billion ($800 million) to the development of 100 airports over the following four years.[11]

In the meantime, legacy hubs in North America and Western Europe are modernizing and enhancing their facilities. Among others, Chicago-O'Hare, Dallas-Fort Worth, Manchester Airport, LaGuardia Airport, and Paris-Orly are developing or redeveloping their passenger facilities within their existing footprint. Various legacy hubs will reach their maximum capacity sooner rather than later with increasing difficulties for expanding further because of the lack of land available and local opposition. Clean-sheet large commercial airport projects are becoming a rarity (Berlin Brandenburg Airport Willy Brandt [2020], the future Polish Solidarity Transport Hub Poland [2028], and the third runway project at London-Heathrow [LHR] are exceptions). When it comes to attracting interconfacing the competition of Middle East airports, which are strategically located between Asia, Africa, Europe, and the Western hemisphere—without being subject to the same social pressure and regulatory constraints.

a Per the UN, the global population is expected to reach a maximum of 10.4 billion around 2085 before shrinking. While this report does not consider the period beyond 2070, the global demand may still grow after the peak as more households should be able to afford travels.

FIGURE 1. 2022-2070 EVOLUTION OF THE WORLDWIDE POPULATION

Source: United Nations, Department of Economic and Social Affairs, Population Division. (n.d.). World Population Prospects 2023. Retrieved from https://population.un.org/wpp/

Paradoxically, our world is becoming freer overall, facilitating the emergence of more stable, open, and inclusive societies. Since the beginning of the 20th century, extreme poverty and child mortality have fallen, while literacy rates, life expectancy, and the percentage of humans living in democracies have risen.[14,15,16,17,18] However, the march toward progress is never a straight path.[19,20] Recent years have seen a revival of violent speech and partisanship, including in the most developed countries.

A WEALTHIER, MORE DEMOCRATIC SOCIETY OPEN TO THE WORLD

Civil wars and terror groups are on the rise.[12] These conflicts deeply impact communities and infrastructure, and they force populations to move. Conflicts and the overall security situation in several regions of the world severely prevent the development of air service, isolating these countries further and depriving them of economic opportunities.[b]

It was once thought that interstate conflicts were now on the verge of extinction.[13] These wars are back including at the immediate borders of the European Union. In 2022, the Russian invasion of Ukraine marked the largest attack on a European country since World War II. The conflict significantly impacted civil aviation due to airspace restrictions and sanctions limiting the overflight of both Ukraine and Russia. Additionally, many Ukrainian commercial airports have been targeted by Russian strikes.

Regional integration and interregional agreements (Fig. 2) have strengthened peace and mutual prosperity. They have removed international barriers to commercial aviation as well. Open sky agreements between countries, combined with the liberalization of air transportation, have benefited the industry and customers alike by increasing the number of and decreasing the cost of airfares. After Europe[c], Africa and Southeast Asia are on their way to become the next integrated single aviation markets; however, implementing these initiatives

b For example, while the United States is a top trade partner for Kenya, further trade development (e.g., tourism) was hurt for many years due to the absence of direct flights. Previous direct services were suspended over security concerns. Finally, Kenya Airways started flying to JFK in 2018.

c The European Common Aviation Area (ECAA) allows any airline incorporated in a member state to operate between two airports within the Area – a key to the success of pan-European air carriers such as EasyJet and Ryanair.

is challenging. The Single African Air Transport Market, incepted in 2018 under the umbrella of the African Union's Agenda 2063, is still a work in progress.[21] Of the 37 countries that initially signed the agreement, only 18 have completed full submissions.[22] In the Asia-Pacific region, the completion of the Association of Southeast Asian Nations Single Aviation Market (ASEAN-SAM) is struggling with opposition from members to grant third, fourth, and fifth freedoms of the air to other member states.[23]

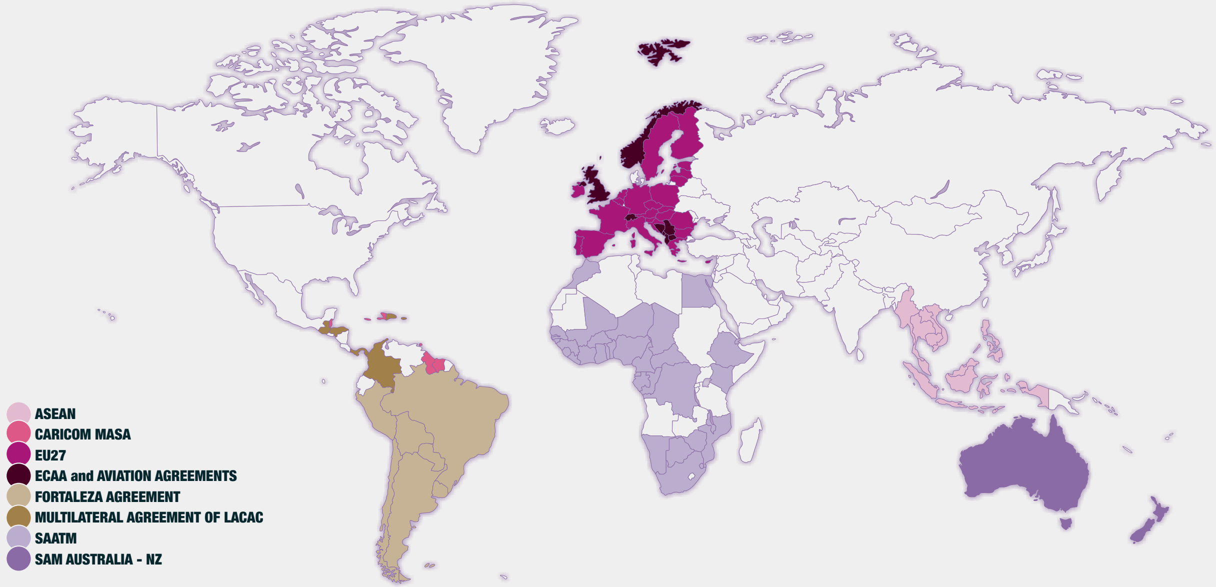


FIGURE 2. EXISTING AND EMERGING SINGLE AVIATION MARKETS

Source: Hoornweg, D. & Pope, K. Population predictions of the 101 largest cities in the 21st century. Global Cities Institute, 2014

URBAN CIVILIZATION AND LOCAL COMMUNITIES

The "last frontier" to the competition is the limitations on foreign ownership and control of airlines. In most countries—including the United States and countries within the European Union—foreign entities cannot control more than 49% of a domestic air carrier. Operators such as AirAsia and FastJet are circumventing current restrictions in Southeast Asia and Africa, respectively, by creating national affiliates in partnership with local investors under the same branding. In 2019, Brazil repealed most limitations on foreign ownership and control.[24] The same week, Grupo Globalia (Air Europa) applied to operate domestic flights in Brazil.[25] Further liberalization could offer new air service opportunities in countries where sustainable national champions have failed to emerge. With potential mega-mergers among Asian, European, and North American air carriers, the prospect of a more concentrated air market is also possible.

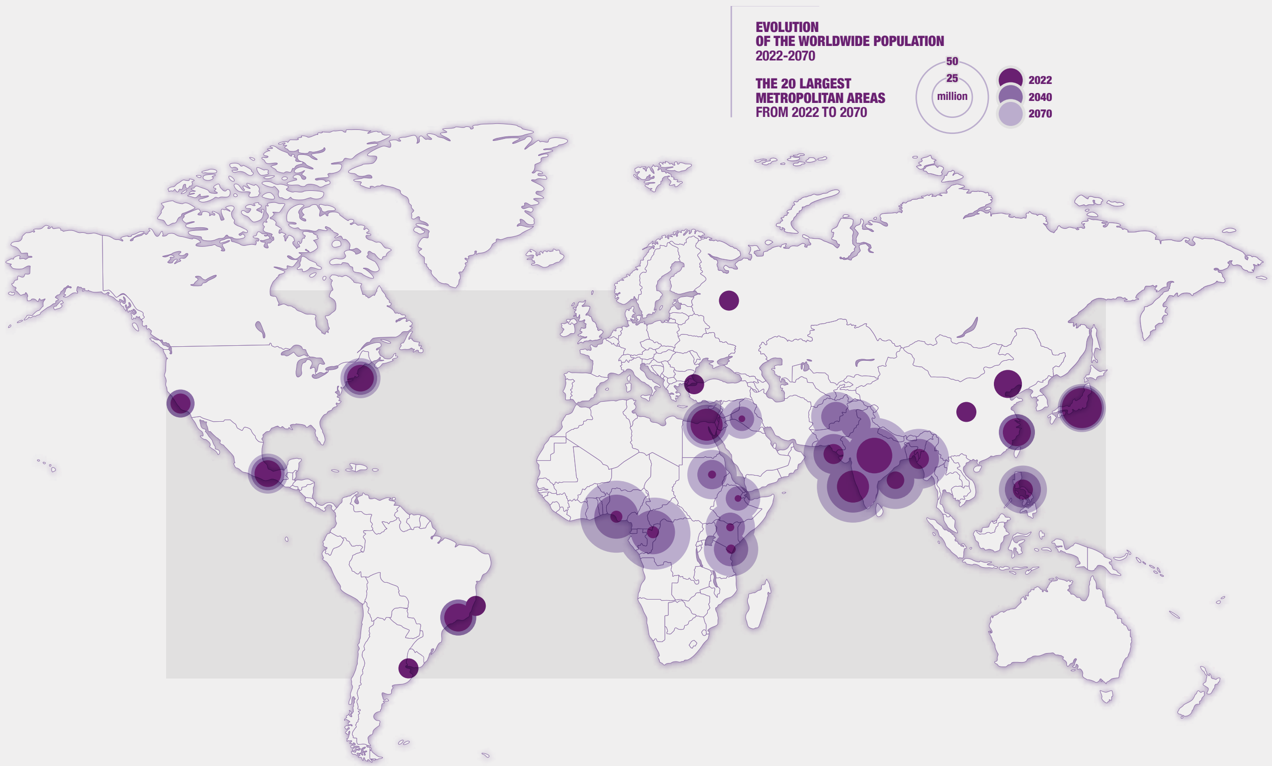
About 55% of the worldwide population already lives in urban areas. This percentage will increase to 68% in 2050.[26] In the United States, where about 80% of the population lives in cities, 11 megaregions of higher urban density might appear by 2050.[27,28,29] By the end of the century, the five most populated metropolitan areas will be in Africa and India–each one with over 55 million inhabitants (Fig. 3).[30] Only Delhi is part of the top five today. The continued growth of megalopolises creates challenges in intraurban mobility but could also deliver new aviation megacities. Legacy mass transit solutions can significantly improve airport access for all. Emerging mobility, such as connected and autonomous vehicles and urban air mobility (UAM), have the potential to enhance services—but they cannot address acute congestion symptoms alone.

FIGURE 3. 20 LARGEST METROPOLITAN AREAS FROM 2022 TO 2075

Source: Hoornweg, D. & Pope, K. (2014). Population predictions of the 101 largest cities in the 21st century. Global Cities Institute; Institute for Economics & Peace. (2022). Ecological Threat Report 2022–Analyzing Ecological Threats, Resilience & Peace.

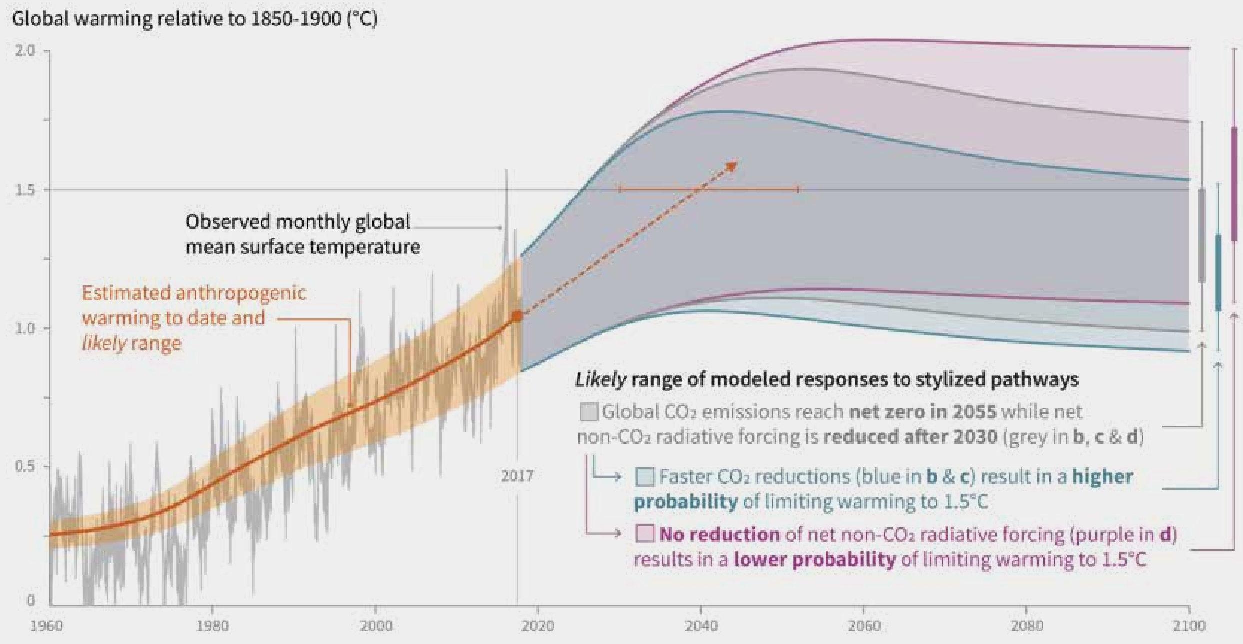
The large footprint of megacities and transit issues might promote multiairport systems and secondary airports. At the same time, smaller and rural communities will still host a significant population. Some might revive and grow with citizens and workers looking for another way of life and more affordable costs of living, away from housing crises and the skyrocketing cost of living that plague many large cities. The most dynamic of smaller and rural communities are sometimes referred to as "zoom towns."[31] The dissemination of intelligent technologies[d] and new production processes are making these communities more attractive by enhancing accessibility to goods and services and by improving their accessibility and connectivity. Because of this, regional and smaller airports will continue to play a vital role in enabling services to larger hubs. Point-to-point flights between regional cities will provide transverse, secondary routes contributing to the socioeconomic development of some regions. From 2021 to 2023, 44 new markets were opened by such airports in the United States.[32]

The emerging world does not want to be considered as the low-cost manufacturing facility and the landfill of the world anymore. China has encouraged investments in higher technologies.[33] Indonesia, Malaysia, and the Philippines are refusing deliveries of Western trash.[34,35] Wages have increased in these countries. Carbon taxes on transportation are in discussion. Producing on the other side of the world is not as profitable as it used to be. At the same time, workers of Western nations ask for relocating production and jobs. A growing number of consumers buy locally and call for a more circular economy. Global issues, regional crises, and local incidents are challenging intercontinental supply chains. The *relocalization* and decentralization production are fostered by a revolution in tooling and industrial processes (e.g., three-dimensional [3D] printing) that will impact the shipment of freight worldwide, including air cargo.



d Intelligent technologies apply technical knowledge to generate and execute functions that can solve problems without human input. The best-known example is artificial intelligence (AI).

FIGURE 4. OBSERVED GLOBAL TEMPERATURE CHANGE AND MODELED RESPONSES TO STYLIZED ANTHROPOGENIC EMISSION AND FORCING PATHWAYS



Source: Intergovernmental Panel on Climate Change. (2018). Summary for Policymakers. In Global Warming of 1.5°C. Retrieved from https://www.ipcc.ch/sr15/chapter/spm/

THE EFFECTS OF CLIMATE CHANGE

The correlation between human industrial activities and global warming has been widely documented since at least the 1950s.[36] There is a large scientific consensus on the severity of climate change and its main mechanisms (Fig. 4). The Intergovernmental Panel on Climate Change (IPCC) of the United Nations stated in October 2018 that "limiting global warming to 1.5°C would require rapid, far-reaching and unprecedented changes in all aspects of society."[37] Subsequent reports from the IPCC and other panels such as the U.S. Global Change Research Program have reiterated the same warnings. Ongoing policies and the current course of actions are mostly lagging behind the goals set in 2015 during the United Nations Framework Convention on Climate Change, also known as the Paris Agreement.[38,39] Significant impacts on ecosystems and human health and well-being will occur over the coming decades—and some of them are already happening.

The consequences of climate change will vary from one region to another. For instance, coastal airports will be more often threatened by catastrophic flood. Conversely, some inland facilities will observe extreme temperatures, penalizing aircraft payload more frequently. These changes will impact many aspects, if not all, of airport management and operations. They will increase both capital expenditures and operating costs, and result in more frequent flight disruptions.[40] To combat these effects and more, airports must evolve to reach net-zero emissions as soon as possible.[41]

Facing the most challenging threat of human history, airports and the aviation industry in general will continue their unprecedented effort to lower their environmental footprint. Accounting for about 2% of carbon emissions and 3.5% of the drivers of climate change, the aviation community worldwide has committed to achieve net-zero emissions by 2050. This goal has been set by the industry through its Fly Net Zero roadmap before gaining traction at the International Civil Aviation Organisation (ICAO) level with a Long-Term Aspirational Goal.[42,43] Over 120 airports have reached carbon neutrality per the Airports Council

International (ACI) World Airport Carbon Accreditation program (Level 3+ and above).[44] Several aviation facilities go beyond neutrality and have aggressive plans to further reduce direct emissions—sometimes in line with broader local or national policies. Still, a "plane-bashing" movement has developed in Western Europe supported by lawmakers advocating for a ban on short-haul flights, although the net impact of such measure is questionable and highly variable from one route to another.[45,46] In addition, prohibiting short-haul flights may induce adverse effects, such as increasing the overall emissions of transportation, depending on the policies enacted and the reality of local alternatives to aviation.[47] Although the industry must change, educating citizens and decision-makers on what aviation accounts for, what it brings to society, and what it is doing to combat climate change is essential.

GENERATIONAL BRIDGE OR GENERATIONAL GAP?

Human beings are living longer than ever. Life expectancy is improving worldwide while fertility rates are decreasing. In the near future, the global population will include a growing number of people aged 60 years and over (Fig. 5)—two billion by 2050. These older adults will be healthier and wealthier than those in the past, which will require societies to think differently, be more inclusive, and design the world—including transportation—accordingly.[48] Japan leads the way in this domain. More than one-third of Japanese residents are at least 60 years old, providing important lessons learned to the entire world.[49,50]

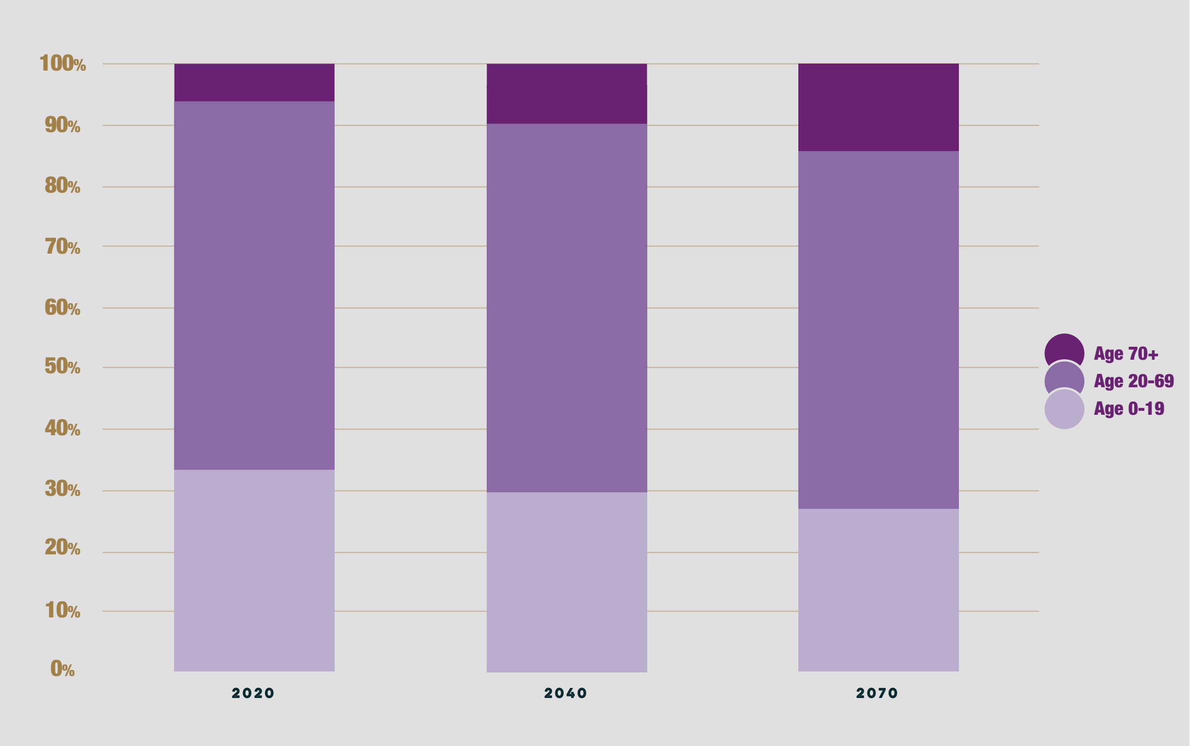
At least half of the passengers during the years 2040 and 2070 have already been born. While the 60-year-olds of 2040 grew in a period of relative prosperity and optimism, the 30- to 50-year-olds will have spent their childhood in the post-9/11 era, during the Great Recession, the aftermath of the COVID-19 pandemic, and the rise of social contention. How will these large-scale socioeconomic events affect social psychology?

Children born after 2000 grew up with new technologies. Hyperconnected, the communities of 2040—and furthermore 2070—will not have the same notion of time and space. Adults currently spend about 6 hours each day in front of a smart electronic device—half of this time on their mobile phones. Fifty years ago, the news took days to reach the world and it was dispensed by authoritative sources. Acquiring knowledge required pursuing a degree or finding a physical library with adequate books of reference. Paper-based bureaucratic processes took weeks and months. Institutional media provided information curated and verified by professional journalists.

Today, internet users have instant access to more material than is possible to read in a lifetime. Lectures from the best experts are available online for free. News reporting is instantaneous—but not always curated and verified. Fake news is commonplace and often spreads purposely to influence public debate. Artificial intelligence (AI) offers new tools to generate highly realistic false information.[51] Social expectations are evolving as well under the influence of technologies. Waiting in a line is no longer acceptable. Passengers want full transparency of fares and rules; simplicity and instantaneity of processes; dematerialization; automation of bureaucracy; no queue anywhere; and personalization of the airport experience at any step. In addition, surveys show that passengers over 55 want to keep human interaction in the loop.[52]

FIGURE 5. PROJECTION OF AGE DISTRIBUTION FROM 2020 TO 2070

Source: United Nations, Department of Economic and Social Affairs, Population Division. (2019). World Population Prospects 2019: Highlights. Retrieved from https://population.un.org/wpp/Publications/Files/WPP2019_Highlights.pdf



A BRIGHTER FUTURE CANNOT MAKE US FORGET PRESENT RESPONSIBILITIES AND UPCOMING CHALLENGES

Oppressed communities showed exceptional resilience and resolution in the decade since 2010. They did not hesitate to take the streets to topple dictators confiscating democracy. At the same time, in most of the developed and developing world, various movements seem to rebuke the model of liberal democracy built over the 20th century. Many of citizens throughout the world have asked for more social justice and transparency and have protested over nation-specific issues. Citizens challenge institutions and doubt the promises to deliver freedom and progress for all after post-Cold War democratization. In a recent survey in South America, less than 25% of respondents declared being satisfied with democracy in their country, and less than 50% of them prefer democracy to other forms of government—the lowest rates since 1995

Some want a more participatory democracy, or at least a better representation of their aspirations. Others do not want to be the forgotten of the unpreceded improvements our society is experiencing. Some call for more social and environmental justice, while others want more individualism. The fear of the other competes with fears of extinction. While society has achieved a level of development unprecedented in the history of humankind, and while the pace of progress has never been as fast as it is now, humanity is full of paradoxes that need to be addressed.

To continue providing safe, efficient, and reliable air transportation infrastructure, the airport industry and its stakeholders must adapt to future challenges and sustainably address the expectations of passengers, neighbors, and citizens.

CHAPTER 2

SUSTAINABLE BUSINESS MODELS AND NEW SOURCES OF FUNDING

TOWARD MORE INDEPENDENT AIRPORT OPERATORS

During most of the 20th century, airports were planned, built, and operated by central governments as tools of sovereignty, prestige, national defense, and economic development. Over this period of economic interventionism, airports were entrusted to the public administration—often ministries, national aviation authorities (United Kingdom, 1923–1965; Malaysia, 1969–1991), public agencies (India, 1972–1995), or public companies (Brazil, 1973–present; France, 1945–2005; United Kingdom, 1965–2006).

From 1980 to 2010, most countries in which airport operators were under the same branch of the government as the safety oversight agency and the air navigation service organically separated. In the context of growing ancillary activities and capital expenditures, these agencies were transformed into organizations created to develop and operate airports, often with a private corporation statute with a majority government control. This move has promoted a culture of efficiency and enabled the airport governance itself to be more independent from political agendas. Also, it has ensured an independent oversight and economic regulation of airports by governments.

Today, while airport ownership is mostly retained by central or local governments around the world, the development and management of these facilities are increasingly being transferred to or contracted with private equity airport management firms. In Canada, airports are leased by the federal government to non-for-profit airport companies. State-owned private corporations operate most airports in Northern Europe and Southeast Asia. Public agencies or companies remain a popular model in Africa, Middle East, and Central Asia. However, many of these countries are transitioning toward public-private partnerships (PPP) through concessions (e.g., Brazil, Greece, Mexico), partial privatization of individual airports (e.g., China, Saudi Arabia), or other agreements (e.g., Tanzania, Turkey). Overall, private sector operators perform better than their public counterparts when it comes to generating traffic, efficiency, and quality.[53,54]

Because of history and local specificities, most U.S. airports are managed by city or county departments.[55] The Port Authority of New York and New Jersey (PANYNJ) is a body controlled by two U.S. states (also known as an interstate compact) created for developing and operating vast transportation assets—including the Newark Liberty International, John F. Kennedy International, and LaGuardia Airports—and real estate. These three facilities have undertaken important redevelopment efforts through PPPs. The State of São Paulo, Brazil privatized 22 airports in 2021 under public–private partnerships.[56] Created as a statutory authority in 1994, the Airports Authority of India operates 126 airports and provides communication, navigation and surveillance (CNS) and air traffic management (ATM) services as well. The Alaska Department of Transportation owns and operates a statewide airport system comprised of 237 facilities—the majority of them providing an infrastructure vital to remote rural areas.[57]

PRIVATIZATION AND GLOBAL COMPETITION

Airport privatization might be seen as the next step of state-owned corporatization. It can take different forms–concessions of the entire airport, Built-Operate-Transfer (BOT) and Design-Build-Operate (DBO) of

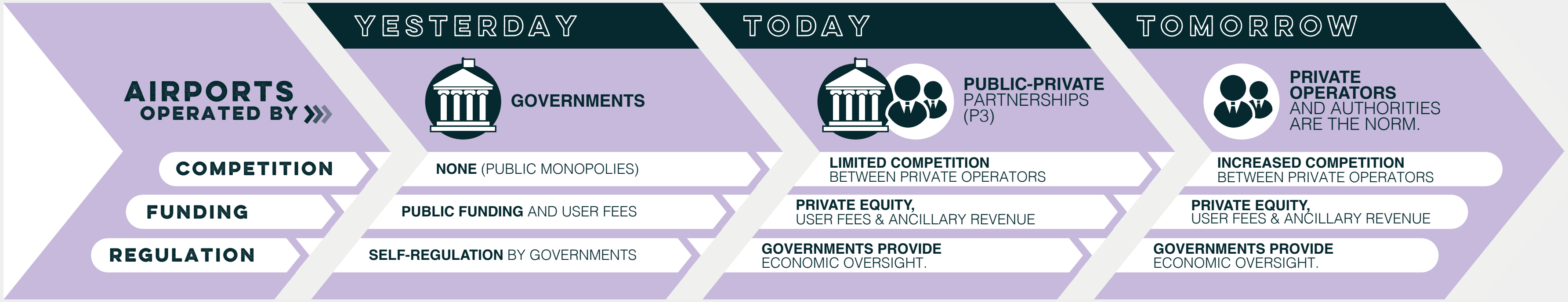


FIGURE 6. EVOLUTION OF THE AIRPORT MARKET AND REGULATORY ENVIRONMENT

individual facilities (e.g., passenger terminal), etc. There are privatization projects in virtually all the regions of the world. Public control of airport management is not considered as a necessity anymore, and private operators are seen as more versatile, cost-efficient, and innovative. Therefore, governments can focus on market regulation and safety/security oversight. While separation with national aviation authorities can provide better overall governance, privatization is a more radical move from state-interventionism in transportation (Fig. 6).

In the United States, few airports are privatized under the traditional concession model "from the curbside to the runway." San Juan Luis Muñoz Marín International Airport (SJU) is the only airport successfully transferred to a private operator through the Federal Aviation Administration (FAA) Airport Investment Partnership Program (formerly known as Airport Privatization Pilot Program).[58] Orlando Sanford International is operated by a private firm through a joint-venture with the Airport Authority. Branson Airport in Missouri is the only privately owned and developed commercial service airport in the United States. However, U.S. airports are more privatized than it may appear initially.[59] Many terminal facilities have been developed and funded by air carriers and various forms of PPPs exist. For instance, LaGuardia Gateway Partners operates the Central Terminal B at LaGuardia Airport under a concession agreement with PANYNJ.

In Europe, where airport privatization was pioneered, former public operators grew into horizontally integrated groups seeking international expansion (e.g., Aeropuertos Españoles y Navegación Aérea Aeropuertos, Fraport, Groupe ADP [formerly *Aéroports de Paris*], Royal Schiphol Group). Hub airports in Asia and the Middle East have relied for decades on expertise from leading Western firms to bloom. These organizations have gained in maturity and experience. They are constituting their own design bureau and project management offices. They have grown as business-oriented corporations and now compete with already well-established consultancy firms and airport management groups to win contracts abroad.

The ownership of airports can be controversial. Airports were originally developed with taxpayer money and have massive implications on land use and the local economy. Because they benefit and impact their communities, countries have transferred full ownership of smaller airports to local

TABLE 1. EVOLUTION OF AIRPORT OWNERSHIP AND MANAGEMENT

YESTERDAY (20TH CENTURY)	TODAY (2000–2030)	TOMORROW? (TOWARD 2070)
• Airports operated by government • State-monopolies • National assets • Policy-driven offer *Airports are public assets operated by Department of Defense or Transportation. Offer is largely piloted by government.*	• More airports operated under private-public partnerships • Little competition between operators • Government ownership of infrastructure • Market-driven offer *Former public airport operators' team with investors for finding external growth with concessions.*	• Private-public partnerships and Authorities are the norms • Global competition between operators • Local, private, and foreign ownership • Market-driven offer *Open competition between airports. Secondary airports capture more point-to-point markets.*

Source: Hoornweg, D. & Pope, K. (2014). Population predictions of the 101 largest cities in the 21st century. Global Cities Institute; Institute for Economics & Peace. (2022). Ecological Threat Report 2022–Analyzing Ecological Threats, Resilience & Peace.

administrations (France, 2005).[60] In the United States, the federal government does not own civilian facilities that were turned to cities and counties after World War II through the Surplus Property Act of 1944.[61] Retaining ownership and signing concessions, BOT or DBO ensure the continuity of operations and facilitate transfer to another firm—a choice that Brazil has made. Canada, where the federal government owns airports and grants concessions to nonprofit operators, considered a full "privatization" (sale) of these assets to the private sector. This project was suspended in 2018 because of the strong opposition from both airport operators and air carriers. The future will see more diversity in ownership, with local governments and the private sector teaming together for managing and developing these facilities, and more flexibility toward foreign investments (Table 1).[a]

ECONOMIC VIABILITY OF PRIVATE OPERATORS

Airports compete on large catchment areas over air fares, accessibility, connectivity, and the level of service.[62] At the same time, they are largely monopolistic businesses at the local level, even in metropolitan areas served by multiple aviation facilities. Because of their footprint and massive cost of development, they cannot fall under the characteristics of a fully demand-driven, oligopolistic market. In other words, a competitor cannot build a new airport nearby another for expanding the offer. Consequently, governments must provide economic oversight and regulates operators to protect consumer interests. Most of the time, airports decide on airport charges and short-term investments with their stakeholders under the umbrella of an independent regulating body through pluriannual plans or contracts of economic regulation. Profit margin and airport charge capping are popular negotiation tools.

Commercial service airports must be allowed to fund infrastructure maintenance and realistic development adequately through reasonable facility

a See Appendix B: Current Examples and Trends on Airport Business Models.

charges as they can no longer rely on taxpayer funding. Airport concessions and other PPP must enable a fair distribution of the profit and financial burden between the contracting parties. Unrealistic goals in terms of investments can challenge the financial viability of airport operators as infrastructure development and capital improvement require a consequent influx of money. Such conundrum led to the bankruptcy of Aeroportos Brasil SA, the former consortium operating Viracopos International Airport, Brazil, in 2018. [63] Operators will get always more creative at generating ancillary revenues and attracting new activities on airport land.

Commercial airports need to generate an acceptable profit to fund their infrastructure without cash inflow. In Europe, airside improvements are largely funded through aviation facility charges negotiated with the airlines to provide for five-year capital improvement programs. Passenger terminal buildings are generally paid with money borrowed from banking institutions or public investment banks such as the European Investment Bank (EIB). These considerations do not always apply to smaller airports. Their financial equilibrium is sometimes precarious without a public contribution to cover their loss. While some of them might not be profitable, the public service they provide and their direct and indirect impacts on the local economy should be considered. Brazil is experimenting with an innovative approach to the privatization of secondary airports through regional "packages" of individual facilities with different profit prospects. Bundled airport privatization was also attempted in Japan.[64,65]

Many remote aviation facilities provide a vital access to isolated communities through air ambulance, cargo delivery, public administration, and mobility enabled by air transportation. They will retain this status of public service and may require financial support to exist. These are community lifelines that cannot be profitable and are not intended to be. Smaller airports with currently underutilized capacity may find a new life as multimodal centers, leveraging regional air mobility and autonomous ground transit vehicles. A new class of small aviation facilities might emerge in metropolitan areas with vertiports supporting UAM. They may be developed by local governments, private developers, airport management companies, flight operators, or even original equipment manufacturers. Supporting the emergence of UAM should not divert resources from other modes—especially mass transit. Also, the use of public policies and assets for facilitating implementation should be tied to conditions to prevent local monopolies and ensure a fair competition between future flight operators and mobility providers.

SUPPORTING AIRPORTS MODERNIZATION AND THE DEVELOPMENT OF THE NATIONAL INFRASTRUCTURE

Several programs exist around the world to ensure that airports are safely developed and meet the needs of the nations and regions they serve. In the United States, the Airport Improvement Program finances up to 90% of eligible projects that enhance capacity, safety, or security at airports of national interest. This federal program is entirely funded by taxes on plane tickets and aviation fuel (trust fund). In Canada, the Airports Capital Assistance Program assists regional airports specifically. In Switzerland, safety upgrades are eligible for federal grants from a national transportation fund. In Brazil, mechanisms exist to support smaller airports serving local communities. However, several of these programs have shown their limits with the available funding

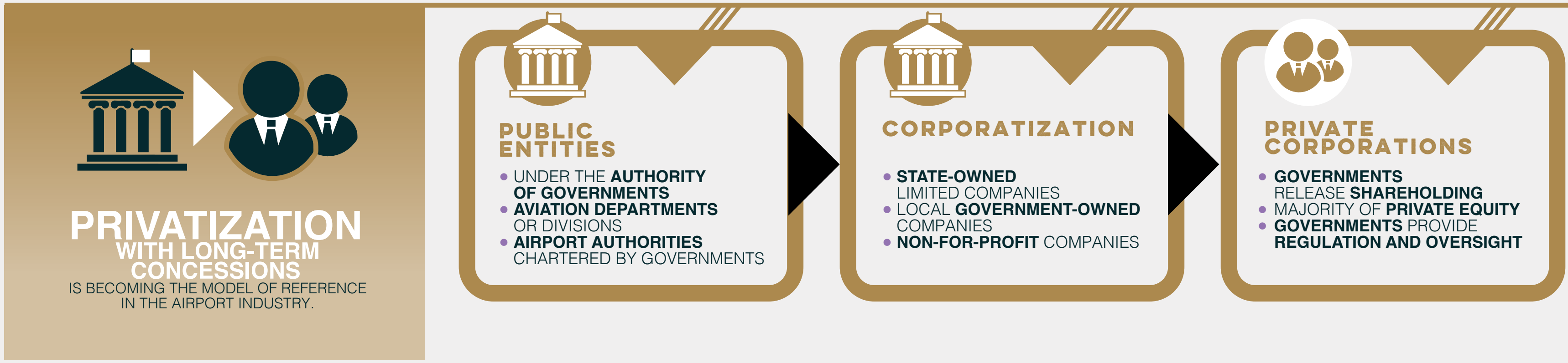


FIGURE 7. FROM PUBLIC ENTITIES TO CORPORATIONS: EVOLUTION OF GOVERNANCE AND OVERSIGHT

not always meeting the overall need.

These funds usually exclude terminal facilities from grants. How do operators rejuvenate and develop passenger terminals without massively increasing the debt ratio or involving air carriers? In many countries, public investment banks can lend money at lower interest rates for this purpose, as long as the operator is based in the country (BNDES, EIB).[66,67] In the United States, while bonds have been a major source of funding, new strategies have emerged. For instance, Paine Field in Washington State has entrusted private developers to build and operate the passenger terminal building.[68] In developing countries, regional banks (African Development Bank) or the World Bank can support large infrastructure projects. In every case, airport operators and local governments must carefully balance the opportunities created by these projects and their level of risk to prevent nonviable investments to mobilize previous financial resource.[69,70] Good management, a realistic business model, a resilient strategic vision, and robust business partners are important factors to the long-term success of airports.

Assuming these conditions are met, airports are usually safe long-term investments that banking institutions, hedge funds, and investors praise. Grants are sometimes more controversial and might not always be accepted by taxpayers. Concessions to private operators of infrastructure developed with public money raises the question of a fair return on investment to governments. (Fig. 7) The US and Canadian examples are interesting, as their national airport infrastructure grant programs are based on user fees (passenger ticket and fuel charges). The fundamental principle is "aviation shall pay for itself."

However, in regions with privatized operations, temporary governmental support and economic relief might be needed during periods of exceptional calamity, like with any other segments of the economy. The 2020 COVID-19 pandemic is an example of what a prolonged, forced period of slowdown in air traffic can do to airport finances. Operators should be reasonably and momentarily supported through government loans and other mechanisms to maintain them afloat. Other stakeholders should be considered for temporary assistance–fixed-base operators, repair shops, ground handling service providers, small businesses, and contractors.

FUNDING INNOVATION: THE VITAL ROLE OF GOVERNMENTS AND INSTITUTIONS

Investing in innovation is crucial not only for the industry but for the air transportation ecosystem entirely. Some airport operators have the ambition to be leaders in innovation. San Diego International Airport (SAN) invites innovators to test their technologies with its Innovation Lab. Groupe ADP has invested in different startups (e.g., Safety Line, Innov'ATM) and has various initiatives to promote innovation such as the Airport Startup Day and the Play Your Airport challenge. Avinor is the national coordinator of the electric aircraft roadmap of Norway. ACI and International Air Transport Association are exploring together the future of airports with NEXTT.[71]

However, the groundbreaking trends and transformational changes that will be explored further in this paper require wider efforts supported by national policies and funding. For instance, programs such as NextGen in the United States and the Single European Sky Air traffic management Research (SESAR) project in Europe have prevented acute airspace congestion. Similar programs of airspace modernization are following worldwide under the guidance of the ICAO Global Air Navigation Plan (GANP) (e.g., Sirius in Brazil). The step beyond will be the introduction of more automation and new concepts of operations supporting aerial innovation. This step will require similar efforts for developing and implementing AI and machine learning (ML) technologies that can further assist pilots and controllers (e.g., RECAT-3) and provide decision-making without a human in the loop when needed (e.g., autonomous aircraft under FAA's extensible traffic management [xTM]). Other domains than air traffic management, such as cybersecurity, might need similar national and regional initiatives.

During the 2019 Transportation Research Board (TRB) Annual Meeting, state departments of transportation warned the audience on the lack of skills and means they foresee with emerging challenges such as uncrewed aircraft systems (UAS) and cybersecurity. Institutional leadership is much needed, especially with smaller airports and local agencies that cannot have specialized staff or fund research projects. These changes will require adapting educational programs from universities and a change in agency staffing or outsourcing. Globally, international institutions, and especially ICAO, will need to provide guidance and standards to operators. ICAO regional coalitions and global plans will help implement these standards and advance the less developed countries.

Beyond governmental action, coalitions of airport professionals under the umbrella of aviation institutions have proven themselves to be a powerful source of innovation and knowledge. In the United States, the TRB has produced research studies and practice-ready materials beneficial to the industry beyond the U.S. borders. Regional airport associations are roundtables for sharing expertise between airports of all sizes, and providing support and representation to smaller airports that cannot afford a large staff. The French-Speaking Airports (UAF&FA) has released innovative recommended practices and practice-ready materials that later became industry standards on topics not covered by regulations. Specialized associations, such as the National Fire Protection Association or SAE International, are normative bodies in their domain.

CHAPTER 3

SMART AIRPORTS AT THE ERA OF INFORMATION TECHNOLOGIES

SMARTPHONE APPLICATIONS AND BIOMETRICS ENHANCE PASSENGER EXPERIENCE

Information technologies have already revolutionized the passenger journey. Travelers exchange data with airlines and airports via their smartphones, and in return they receive personalized information. From mobile applications, checking in for a flight, obtaining an electronic boarding pass, and printing bag tags at home are all possible. These steps once relied entirely on in-person, paper-based processes at the airport. Several airline applications can now perform more complex operations, such as purchasing a ticket or modifying a reservation. Transactions can be confirmed with biometric information–fingerprints or facial recognition, depending on the device. Airports, too, have their own applications. They can send alerts on flight status, facilitate parking payments, and send customized promotional offers in partnership with the airport tenants. They also support the loyalty rewards programs of certain airport operators, such as Groupe ADP, Heathrow Airport, and Changi Airport.[72]

Passengers can interact with their surroundings throughout the facilities via their smartphone. Bluetooth beacons and near-field communication tags share personalized commercials and special offers based on customer location and preferences.[73] For example, the Miami International Airport has installed more than 400 Bluetooth beacons in the terminal. The beacons provide georeferenced information and can facilitate the journey through this large hub airport. Text-to-speech functionality has also been added to many airport websites. These innovations and others (e.g., augmented reality [AR], holograms, and robots) can improve wayfinding for people with special needs, including a growing number of elderly travelers, and increase accessibility and inclusion.

Web-based information is also helpful to passengers. Many travelers cannot read the foreign languages printed on airport signage. Web-based information can provide wayfinding to travelers in their native language. The Paris Aéroport application provides content in French, English, Spanish, Russian, Simplified Chinese, Cantonese, Japanese, Korean, German, Portuguese, and Italian. Leveraging AI and translation engines can be a cost-effective way of making airports accessible, as the Greater Orlando Aviation Authority (Orlando, Florida) discovered after making over 100 different languages available on its website. This is also an opportunity for airports to give visibility to native, minority, and endangered languages without a costly duplication of the physical signage.

Passengers also use applications from local transit agencies,[a] taxi companies, and Transportation Network Companies for the last miles to and from their destination. Airports are now connecting their applications to provide a unique portal of services and mobility to and from airports. These apps compare transit times and costs, creating transparency between price and transportation modes while also developing the conditions for the emergence of Mobility on Demand. Once these technologies are available, preordering an autonomous vehicle or an electric vertical take-off and landing (eVTOL) aircraft before arriving at the curbside or vertiport. The next step is to integrate modes and

a Transit agencies are implementing “tap-to-pay” solution to pay rides with a smartphone (e.g., Chicago, New York, and Portland).

services that enable the purchase of door-to-door, intermodal journeys with Mobility as a Service.[74]

Airports and air carriers have deployed facial recognition to simplify the passenger journey. For example, facial recognition devices have been deployed to verify the identity at the gate when boarding international flights instead of scanning boarding pass and checking passports by hand. This expedites the process and minimizes the boarding time. In the United States, the Transportation Security Administration (TSA) have implemented this technology to verify travelers' identities at the security checkpoint in addition to scanning their driver's license. Integrated biometric solutions such as this, and when combined with other technologies like self-service bag drop-off kiosks, can increase the automation of control, identification, and queueing processes. By 2040, biometrics will be available at other steps of the journey, from the curbside to the gate.

Crossing a border without having a passport checked by an officer is no longer science fiction. For example, the French Passage Automatisé Rapide Aux Frontières Extérieures (PARAFE) program launched in the early 2000s and is available at seven airports as well as train stations and the Port of Calais. Passengers from the Schengen Area and several other non-E.U. countries with a biometric passport can use their document to access an automatic gate, and then confirm their identity with fingerprinting and facial recognition. In the United States, the Global Entry and NEXUS[b] programs offer U.S. nationals and legal permanent residents, as well as nationals from 16 other countries, a similar service at 75 international airports—some outside the United States. For passengers without Global Entry, Mobile Passport Control allows them to perform the standard operations that precede the physical control of passports by an agent of Customs and Border Patrol. Screening is on the verge of significant changes as well. The TSA is working with the industry to develop the next generation of checkpoints, with expedited processes for the most trusted travelers.[c]

INFORMATION ANDINTELLIGENT TECHNOLOGIES ARE REVOLUTIONIZING AIRPORT OPERATIONS

Building Information Modeling (BIM) is widely used in terminal design and construction. Airport BIM is expanding for asset management and operation purposes as well. Continuing the digitalization of information initiated with Airport Geographical Information Systems (AGIS), Airport BIM is opening new perspectives on asset management and airport operations. AGIS was an important element in the implementation of Pavement Management Systems, and Airport BIM is enabling a new world of collaborative tools and can be the vehicle of advanced asset management systems and integrated operations management systems.

The last generation of airfield ground lighting systems is monitored and driven from control centers that can verify the status of each light individually. The condition of aviation pavements (runways and taxiways) during winter conditions can be

b Canadian nationals and permanent residents are eligible to apply for NEXUS and not Global Entry. NEXUS members can use Global Entry kiosks. NEXUS is a joint Canada Border Services Agency and U.S. CBP program.

c See Chapter 4: Security Threats and Unlawful Activities.

reported by sensors too, facilitating the management of snow removal and pavement deicing. By combining pavement monitoring and weather forecasting, airport operators can proactively develop strategies anticipating adverse weather conditions hours before they occur—another domain where ML and AI could open doors. Radar and cameras are already capable of detecting foreign object debris on runways. Using data from the air traffic control radar, it is already possible through analysis to deduct the deceleration profile of aircraft on the runway, detect abnormal patterns, and identify loss of adherence on the runway or unsafe flight operations procedures or practices. If controllers use data on braking action coming from the aircraft, algorithms can generate a nearly real time, aircraft-centric estimate of the runway conditions without having to physically test the pavement with trailers or other devices as it is necessary today.

In Sweden, air navigation services at Örnsköldsvik Airport have been provided since 2015 from Sundsvall–Timrå Airport—125 km away—using a remote tower (rTWR) system. rTWR works with locally based sensors, a secure datalink, and a virtual air traffic control environment (virtual reality). Remote tower centers will increase safety at airports with low-intensity traffic or with flight information services only, where a traditional air traffic control tower is not viable. Moreover, the technologies developed for the remote tower centers might bring AR and other technologies to conventional towers, enhancing the control environment to further increase safety and resilience. The next step might be more automated or perhaps even autonomous air traffic management in portions of the airspace. The emergence of advanced air mobility is pushing for new concepts of operations with remote pilots, control stations, and service providers, ensuring the safe separation of UASs, eVTOLs, and other aircraft in the lower uncontrolled airspace (e.g., UAS Traffic Management, U-Space). Similar concepts are being proposed for high-altitude operations (e.g., xTM).[75]

Airports manage flows of passengers, aircraft, bags, and vehicles. Their waiting time and outflow are the parameters of its efficiency. From the moment the aircraft is at the gate (in-block time) to its pushback (off-block time), the turnaround time should be monitored to ensure the aircraft leaves on schedule. Ground-handling operations involve several functions and different stakeholders. The coordination and supervision of these activities can benefit from intelligent technologies.

Information technology has radically changed this work. At large airports, coordinators who oversee multiple flights from a control center are in communication with field supervisors, who are increasingly equipped with smartphones or tablets for communicating with operations management solutions. Ground handlers no longer rely on individual visual information only. They are assisted by real-time indicators and provided with a broader view on the impact of delayed individual tasks on the performance of the entire flight and of hub operations.

This facilitates the overall management of performance and communication to the Operations Control Center of the air carriers. Ground operations control centers tend to be similar in their organizations and equipment (e.g., the Hub Control Centers of Air France at Paris-Charles de Gaulle and AeroDarat at Kuala Lumpur International Airport are comparable). Such organizations require information systems and connection to other stakeholders' systems, especially under Collaborative Decision-Making (CDM) agreements or similar integration. The next step in ground handling operations at large hub airports might be the introduction of ML and AI to perform real-time and post-operations analysis, detect patterns that create delays, and provide assistance to decision-makers.

SMART AIRPORTS ARE CONNECTED TO THE FIELD AND TO THE WORLD

The need to increase punctuality and minimize the impact of adverse conditions on flight operations led to Airport CDM[76] This concept relies on information sharing between the stakeholders of the real-time status of each flight–defined with "milestones" (defined moments on the timeline of a flight). Each stakeholder is responsible for updating specific milestones–for instance, the ground handler with the target off-block time (TOBT), which is the expected moment the flight will be leaving the gate. A software solution typically consolidates these inputs and delivers takeoff times. With A-CDM, the airport community, including air traffic control, can work with target times that take into consideration the reality of the field instead of theoretical estimates. Reducing uncertainty and increasing transparency make operations more efficient and resilient.

The extension of CDM concepts to the whole airport is called Total Airport Management (TAM). TAM provides a holistic approach to real-time airport operations, from the curbside to the air. Such a concept is supported by Airport Operations Centers (APOC), integrating the various functions of airport operations (including external stakeholders). TAM connects the entire airport ecosystem—from the crews in the field to enroute centers as needed. APOC can be seen as a center of anticipation, supervision, and decision bringing together all the stakeholders of airport operations, including air carriers, airport operators, air navigation service providers (ANSP), apron management service providers, ground handlers, transit agencies, law enforcement, and immigration forces.

Together, stakeholders monitor flows and capacities in real time, plan and anticipate for the next days, and react to prevent adverse conditions to turn into a crisis. In their task, they are assisted by imagery provided by closed-circuit television and data gathered by sensors in the field. More important, they must rely on agents in the field because sensors cannot address operational issues alone. The acting staff should be connected to their supervisors under the authority of the Airport Operations Manager. A-CDM and APOC empower Airport Operations Managers and their teams as they lower the monitoring workload, assist decision-making with key performance indicators, and provide them with powerful C4I (Command, Control, Communications, Computers, and Intelligence) tools to manage the airport proactively with a comprehensive view of its operations, instead of reactively with a focus on one specific issue. A-CDM and APOC implementation are objectives of the ICAO 2016–2030 GANP.[77]

At a broader scale, the systemwide information management implemented in North America and Europe will provide unified platforms and standards for information sharing to provide a single point of access to Air Traffic Flow Management data. Systemwide information management will provide an information-centric system to support ATM modernization programs such as NextGen and SESAR. As part of ICAO's GANP, it will enable and facilitate a worldwide exchange of real-time information, and connection to a new wide range of applications and users. Today, the ANSPs in Eurocontrol, the U.S. FAA, the *Departamento de Controle do Espaço Aéreo* (Brazil), and the General Civil Aviation Authority (UAE) already exchange flight data in real time–prefiguring worldwide exchanges at the 2040 horizon.

DEEP AUTOMATION AND BLOCKCHAIN COULD DRIVE ANOTHER INFORMATION TECHNOLOGY REVOLUTION

The collection and treatment of such volumes of data require adequate standards and infrastructure to support their transfer and storage. Most commercial airports now have data centers. They will be fed by the IoT (and ultimately the Internet of Everything) supported by 5th generation infrastructure (5G)–and its next iterations. The data themselves have limited value for the airports and their stakeholders. Investing in big data should serve a purpose, and it will depend on the value that could be extracted from these data. Emerging means and processes to analyze data are dramatically expanding the horizon of possibilities. ML and AI can extract patterns and trends from airport operations databases and other stakeholders- or function-specific databases for planning, situational awareness, or decision-making purpose. Deep learning using artificial neural networks and deep automation will be the next step and could assist, supplement, and even replace human analysis and decision-making in domains like operational resource management and asset management. These intelligent technologies could provide analytics and direct assistance to decision-making with "what if" scenarios, a move from current practices (similar to recent changes from reactive management, mainly based on a visual assessment, to a proactive organization, based on indicators that provide a broader vision of the field). Blockchain is another emerging technology based on cryptography that can help with securing the exchanges of information and facilitating approval/validation processes ("contracts") in a wide range of activities such as construction (document reviews, field inspections), operations (ground handling contracts, TOBT updates, aircraft recovery agreements), and regulation (airport certification, security clearances).

The airport industry is aware of the potential of information and intelligent technologies. The larger airports can and want to be at the front edge of this new revolution. San Diego, the Metropolitan Washington Airports Authority, and Groupe ADP have different strategies, ranging from innovation challenges to intrapreneurial labs and even direct investments into startups.[78] In the long run, these technologies will be accessible to regional airports, and even general aviation airports with scalable solutions tailored for simpler facilities and lower traffic. Meanwhile, there is a risk for local governments, smaller airports, and the least developed regions of the world. The industry will work on closing the gap on information technologies as their dissemination will make the whole air transportation system more resilient. In the short term, it is possible to be a connected airport for a few hundred dollars. In 2015, the Executive Director of

Tupelo Regional Airport presented at the TRB Annual Meeting low-cost connected airport systems developed in-house and using the GSM network to send Notices to Air Missions and pilot information by text messages to the pilot community, and messages on the status of emergency generators and fire suppression systems to the airport management.

As airports rely increasingly on information systems and data exchange, they become more vulnerable to any disruptions. Also, new connected technologies make aviation potentially more vulnerable to attacks.[79] Upon transitioning to new systems for supporting their operations, airports should develop information technology resilience and contingency plans for business continuity. Airports are also exposed to cyber-criminality and cyberterrorism. They must consider their cybersecurity aspects. Data gathering and exchange through open or poorly protected networks can create new opportunities for criminal organizations, individual hackers, and state-sponsored groups with hostile intentions. Cybersecurity is now a hot topic worldwide in aviation. During the 2020 Air Navigation Conference of ICAO, nearly all papers included discussion items on cybersecurity.

CHAPTER 4

SECURITY THREATS AND UNLAWFUL ACTIVITIES

EXISTING PATTERNS OF TERROR WILL REMAIN THE MAIN THREAT OF TOMORROW

In 2017, then TSA Administrator Peter V. Neffenger declared that “there is a spectacular nature to attacking aviation. First of all, it says something about you as a terrorist group if you are able to get through all the systems designed to prevent damage. But it also has a huge psychological impact and a very large economic impact.” This was true in 2017 and will still be applicable in 2040 and 2070.

Although terrorism has no limit when it comes to exploiting vulnerability and leveraging new technologies, isolated extremists and larger groups tend to prioritize high-lethality and low-complexity solutions (Table 2).[80] The most common patterns of attacks have remained unchanged since the 1970s.[a] Bombing the check-in counters or baggage claim and attacks with firearms by armed groups in the public area of passenger terminals have been used on multiple occasions. These modes of action maximize damages, casualties, and mediatic impact while they are difficult to prevent unless these efforts are identified prior to their action via intelligence and police investigation.[81,82]

Early checkpoints filtering the access to the airport landside disrupt the flow of passengers, greeters, and workers without addressing the threat as they create bottlenecks, providing an easy target to terrorists.[83] They are not relevant countermeasures. Vigilance from the airport community and awareness of passengers form the first natural barrier. Canine patrols specially trained for detecting explosives are an efficient deterrent inside the terminals at the most exposed airports, as long as both the dog and the handler are adequately trained and comply with standard operating procedures.[84] The next evolution could be a simple walk-through sensors at the entrances of terminal facilities. Microwave radars with ML are already in use at some casinos and banks.[85] Strategically located at terminal accesses, they might constitute an early warning system for detecting weapons and explosives without slowing downflows.

Since the 2000s, radicalized individuals started increasingly ramming cars into the public. Used for the first time in an airport in 2007 in Glasgow, vehicle-ramming attacks have occurred in multiple nonairport locations. The most efficient mitigation strategy remains the protection of the pedestrian part of the curbside as well as checkpoints with reinforced bollards or blocks. Current bollards are typically able to stop 1.5- to 7-ton vehicles (midsize cars to medium trucks) at 50 to 80 kilometers per hour (30 to 50 miles per hour).[86] Systems capable of stopping heavier trucks also exist.

Active shooter occurrences have sharply increased since the beginning of the decade, especially in the United States. Recent events at airports include Fort Lauderdale-Hollywood International Airport (2017) and Dallas Love Field (2022).[87] These mass shootings are perpetrated by mentally unstable or radicalized individuals. These are the most difficult to detect early because they are committed by motivated individuals who can stay under the radar of counterterrorism and law enforcement until they decide to act.

---

a See Appendix C: Selection of Physical Attacks on Airports and Airplanes.

THE NEW FACE OF TERRORISM

After the nationalist and political violence of the 1970s and 1980s, Salafi jihadism led as the main source of terrorist acts against civil aviation in the following decades. In 2014, Iraq and Nigeria accounted for more terrorist violence than the rest of the world. The Islamic State of Iraq and Syria (also known as *ISIS*) controlled significant swaths of Syria and Iraq in the mid-2010s. The group and its followers carried out the 2016 bombing of the Brussels Airport. Though ISIS has since retreated to an insurgent force, its global affiliates continue to plot mass murders. As long as poverty, violence, and political instability plague certain parts of the world, new terrorist groups will rise in the wake of civil war and power vacuums.

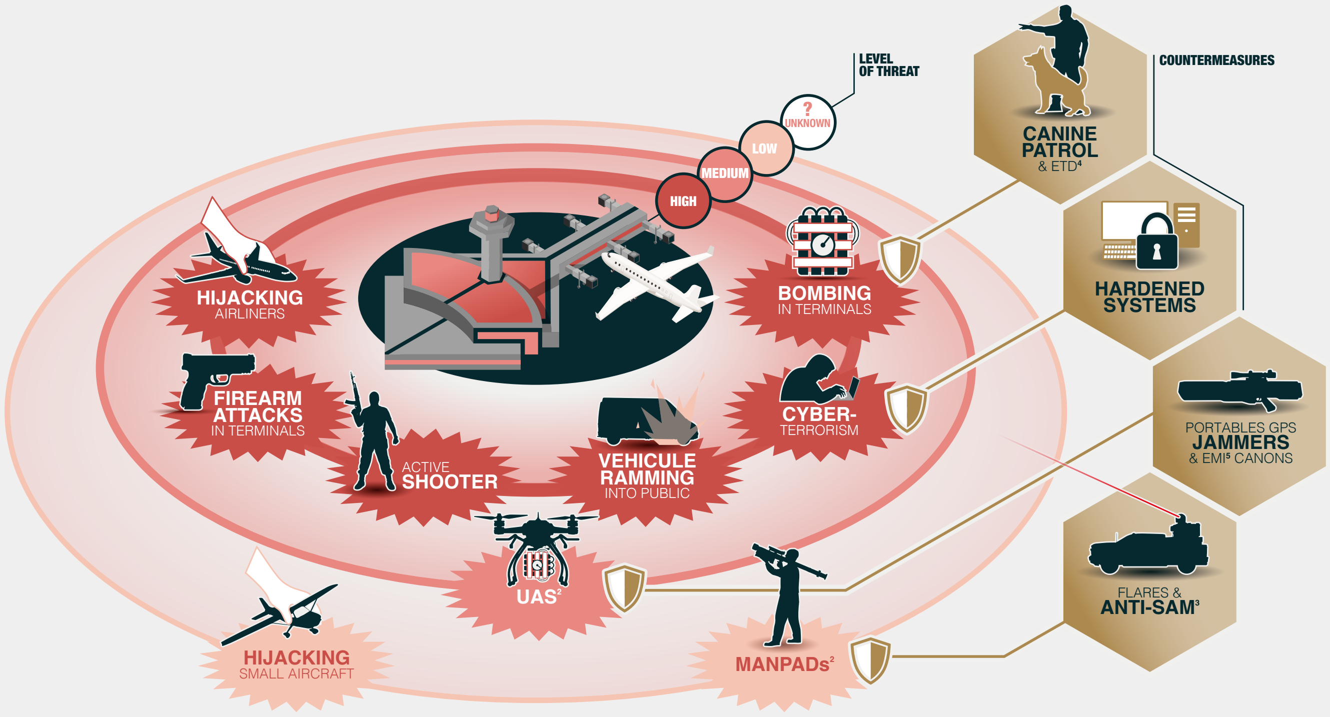
But terrorism is not just an external threat coming from war-torn regions. Over the past two decades, most attacks in developed countries have been perpetrated by domestic terrorists—especially racially and ethnically motivated violent extremists.[88,89,90] Mass shootings in Norway and Christchurch by right-wing extremists should raise concerns over potential occurrences at airports. In the United States, domestic terrorism–related investigations have grown by 357% over the last 10 years.[91] In the last few years, instances of politically motivated domestic terrorism include the January 6, 2021, assault on the United States Capitol and the January 8, 2023, attacks on the Brazilian federal institutions in Brasília. The January 6 insurrection in Washington, D.C. was followed by an unprecedented surge in violent “unruly passenger” occurrences in the U.S., with nearly 6,000 reports filled in 2021.[92] The Brasília riots were preceded by a bombing attempt before Christmas targeting Brasilia President Juscelino Kubitschek International Airport with the intent of “creating chaos and a siege state in the country” to prevent the president-elect from taking office.[93]

Domestic violent extremists (DVEs) target transportation and infrastructure. Since the early 2020s, some have conspired and attacked the electrical infrastructure.[94] New violent movements will emerge in the future. DVEs can be inspired by various political or religious ideologies. The spread of baseless conspiracy theories (such as the chemtrail myth[95]) can have implications for national security and civil aviation with believers calling for coordinated harassment and physical actions on social media platforms. Ecoterrorism is also on the rise, growing with the frustration of the most radical factions of green activism and anarchist extremism.[96] Members of these groups have already used arson and bombing against private interests, as well as vandalism against public assets and cultural heritage.[97] In 2022 and 2023, airports in Berlin, Madrid, Munich, and Paris were subject to incidents such as perimeter intrusions and property damage—which, paradoxically, generate more emissions through flight delay. Aviation has often been a symbol of capitalism and globalization. Between 1978 and 1995, the “Unabomber” terrorist chose targets associated with the aviation industry and technology sectors, including airlines and at least one commercial flight.

Active shooter occurrences have significantly increased in the recent years and some have happened at airports. Although there is no real template for such violence, perpetrators are often angry, vengeful individuals

FIGURE 8.

TYPOLOGY OF SECURITY THREATS AND COUNTERMASURES



[1]UNCREWED AERIAL SYSTEMS [2]MAN-PORTABLE AIR-DEFENSE SYSTEMS [3]SURFACE-TO-AIR MISSILE [4]EXPLOSIVE TRACE DETECTOR [5]ELECTROMAGNETIC INTERFERENCE

rejecting our society, despising fellow human beings, or contemplating self-harm and suicide.[98] They seek retribution for a perceived harm done by specific people, groups, or institutions. The United States struggles with active shooter occurrences facilitated by the broad availability of firearms, but mass killings are not unique to this country. For example, attacks with knives against school pupils have multiplied over the past few years in China. Mental illness worldwide is increasing. Digital tools help find like-minded audiences, violent videos, hateful manifestos, and tips to commit crimes, all of which can increase deadly thoughts and incite persuadable people to take action.

EMERGING THREATS REQUIRE NEW, SPECIFIC MITIGATION

Man-Portable Air-Defense Systems (MANPADs) have been used sporadically against civil aviation since the years 1970. In 2004, ICAO identified over 40 MANPAD incidents against civil aviation that resulted in about 600 casualties.[99] Radical movements continue seeking acquisition of MANPADs.[100] The proliferation of limited but consistent stockpiles of these systems happened consecutively: the 2003 war in Iraq and the 2011 Libyan civil war. Theoretically, these systems can be stored for long periods of time (up to 20 years). Several hundreds of MANPAD units could be under the control of militias and terrorist groups. More than 50 strikes against civilian aircraft have been perpetrated, with about 30 of them accounting for about 1,000 fatalities. Since 2000, at least three civilian aircraft have been targeted in Eastern Africa and the Middle East. Such threats have cost these airports a delay in the development of air services. Also, the potential economic damage was evaluated beyond $17 billion in 2016 if an attack was conducted at an airport checkpoint in the U.S.[101] While airports are not currently equipped with active countermeasures, overexposed airlines have decided to equip aircraft flying exposed destinations with flares (e.g., Israelian air carriers Arkia and El Al). As anti-surface-to-air missile (SAM) defensive lasers are developed, the most exposed airports could be equipped with such systems in the future.

The return of international conflicts has threatened commercial aviation. Malaysia Airlines Flight 17 was shot down while cruising over Ukraine in July 2014 by Russian-sponsored separatist forces who used a "Buk" SAM system provided by the Russian Federation in support to the Donbas War.[102,103] Ukraine International Flight 752 was struck by SAM Tor M-1 fired by the Iranian Revolutionary Guard Corps shortly after takeoff from Tehran, Iran, after mistaking the airliner for a U.S. cruise missile. Frequent jamming and spoofing of global navigation satellite systems has been observed over and nearby regions of conflict in the Middle East and Eastern Europe.[104,105,106] These direct threats against civil aviation safety have forced aviation agencies and the industry to develop new practices and contingencies, including flight bans over areas and countries at risk.[107,108]

A body cavity bomb or surgically implanted improvised explosive device was detonated at least once in an assassination attempt on a member of the Saudi nobility in 2009. Body cavity bombs are detectable by canine patrols and explosive trace detectors, but they are not by current body scanners. Surgically implanted improvised explosive device are not detectable by current systems unless the bomb holder takes an X-ray. Certain technologies (e.g., nuclear quadrupole resonance) have shown some success in detecting traces of explosive chemicals (e.g., trinitrotoluene [also known as *TNT*] and cyclonite [commonly known as *Royal Demolition eXplosive* or *RDX*]) within the human body without exposing people to radiation or hazardous magnetic fields, they have not been introduced at airport screening checkpoints at this time. Because of the logistics required for implanting the device, the impact of the wearer's body in mitigating the explosive force, and limited blast yield, such weapons are primarily anti-personal bombs rather than massive destruction weapons. However, this threat should not be underestimated.

After the September 11 attacks, members of the intelligence community feared that chemical, biological, radiological, and nuclear weapons could be used by nonstate actors with the particular threat of extremist Islamic terrorist groups accessing fissile or radioactive materials to prepare improvised nuclear devices and radiological dispersal devices. Although some of these groups did consider such options, none of them have ever succeeded in securing significant quantities or gathering the means to achieve the required level of sophistication.[109,110] However, recent progress in bioengineering raises the question of easier access to bioweapon technologies.[111] Clustered regularly interspaced short palindromic repeats (CRISPR) genome editing was the 2015 American Association for the Advancement of Science's Breakthrough of the Year. Compared to previous methods, CRISPR allows for the highly efficient and selective editing of genomes. Could terrorist organizations, rogue governments, or skilled lone-actor terrorists[b] create enhanced pathogens? Airports and other public places could be used to spread such pathogens.

Small UAS (sUAS) are opening a new world of cost-efficient solutions in several domains. They are also available to the general public with very

b In 2001, anthrax spores were disseminated by letters. The attacks, killed 5 people and infected 17 others, was perpetrated by a researcher seeking to revive interest in his anthrax vaccine program.

TABLE 2. LONG-TERM THREATS TO AIRPORT SECURITY

THREATS	PAST EVENTS	OVERALL LEVEL OF THREAT	PREVENTION AND MITIGATION AT AIRPORTS
Mass shooting	2017 Fort Lauderdale-Hollywood Int'l Airport 2016 Ahmad Shah Baba International Airport 2014 Jinnah International Airport	High	• Airport community awareness • Armed law enforcement presence • Firearm detection systems
Terminal bombing	2016 Brussels Airport 2016 Istanbul Airport	High	• Airport community awareness • Canine patrols • Explosive detection systems • Public space design best practices
Cyberterrorism	Various	High	• Airport community awareness • Hardening sensitive networks • Sharing best practices across domains
Vehicle ramming attack	2007 Glasgow International Airport	High	• Bollards • Other reinforced obstacles
Civil unrests and violent protests	2022 Berlin Brandenburg Airport 2022 Munich International Airport	Medium	• Airport community awareness • Contingency plan • Law enforcement presence • Fencing and sensors
Uncrewed aircraft	2019 Heathrow Airport 2018 Gatwick Airport	Medium	• UAS detection systems • Active countermeasures

THREATS	PAST EVENTS	OVERALL LEVEL OF THREAT	PREVENTION AND MITIGATION AT AIRPORTS
Airliner hijacking	9/11 attacks 1994 ALG-MRS hijacking	Low to Medium	• Airport community awareness • Screening process • Cockpit protection against intrusions
Small aircraft hijacking	n/a	Low	• GA community awareness • Airport watch programs
MANPADs	2003 Baghdad International Airport	Low	• Onboard (aircraft) countermeasures • Laser defense (future)
Chemical, biological, radiological, and nuclear attack	2017 Kuala Lumpur International Airport	Low	• Ventilation system design features • Means for containment & treatment

affordable pricing ($50 to $200 [in U.S. dollars]). Multiple airports, mainly in Europe and North America, have reported unlawful drone encounters that have endangered or perturbated air operations. The potential damage for an aircraft colliding with a sUAS is more severe than with a bird of equivalent initial kinetic energy.[112,113] Small general aviation aircraft and helicopters are more vulnerable than large commercial aircraft and can be lost consecutively to bird strikes. An sUAS can also be used to facilitate ingress of restricted payloads (weapons, controlled substances, etc.) into the airport perimeter. These vehicles have also shown potential for warfare and terrorism when attached to or fitted with an explosive charge.[114,115,116]

IMPLEMENTING NEW TECHNOLOGIES TO ENHANCE SECURITY

The implementation of advanced security screening technologies has accelerated around the world with the COVID-19 pandemic, which made the application of certain procedures involving proximity to or direct contact with passengers (e.g., baggage searches and pat downs) difficult. To maintain a satisfactory and compliant level of security, airport operators have implemented many new technologies (e.g., advanced body scanners, explosive trace detectors), all of which largely avoid the need for physical search. Since the crisis has passed, the technologies remain, and their deployment is accelerating and easing controls, making the passenger experience more pleasant. The use of 3D scanners and explosive detection systems for both checked and carry-on baggage inspection dramatically reduces the occurrence of manual search. Furthermore, technology suppliers are developing algorithms involving AI and ML to detect threats. For example, automatic prohibited items detection systems automatically detect firearms and bladed weapons. These technologies improve the passenger experience and increase passenger throughput by simplifying controls and implementing less systematic random or nonrandom baggage openings.

As discussed in the previous section, intelligent airports and connected passengers are a growing target for cybercriminals and cyberterrorism. Transportation accounted for 4.3% of cyberattacks in 2023, with 67% of these incidents involving data leak and extortion.[117] Most of these attacks exploited public-facing applications and phishing.[c] Airport public Wi-Fi, due to its open nature, is less secured than corporate or residential networks; both this and the high traffic volumes make it a regular target of cyber hackers seeking personal information or cyber-ransoming travelers. Large cyberattacks with a strong suspicion of state-sponsorship have skyrocketed as well. Statewide power or internet outages have occurred in Estonia (2007) and Ukraine (2015) following cyberattacks from Russia. Dictators and rogue factions could go further and attempt to destroy the integrity of air transportation. Moreover, viruses targeting specific information system infrastructure could contaminate critical networks and systems (e.g., Stuxnet, 2010).

Sensitive airport systems must be hardened to prevent cyber intrusions. Security systems themselves are exposed as they become increasingly connected. In this domain, collaboration between stakeholders is vital—beyond aviation. Initiatives for sharing experiences and responses are important. Locally, computer security incident response teams can organize exercises to raise awareness and stress-test systems and procedures, including at non-hub airports. But cybersecurity is neither a local or industry-specific issue, and broader initiatives are needed as well. In 2020, a survey conducted by ACI World revealed that 84.6% of airports had implemented a cybersecurity policy, and 61.5% of those surveyed reported being targeted by cyberattacks within that year.[118] The ATT&CK initiative of MITRE Corporation aims at sharing information on threats and countermeasures with an online library and an annual conference.[119]

Active countermeasures have been developed for fighting sUAS incursions. They consist of portable global positioning system (GPS) jammers sending an electromagnetic impulse to the targeted drone that will make it fall or force it to land. Recent efforts in research and development have focused on automated detection and identification as well. "Remote ID" capabilities have been required for registering most sUAS in Japan since 2022 and in the United States since

c See Appendix D: Selection of Cyberattacks on Airports.

2024. Systems have been tested or in the process of being tested at airports in the U.S., United Kingdom, France, and Israel. In the near future, automated or semi-automated sUAS countermeasures could be part of the typical security equipment of large commercial airports.

The use of remotely controlled or automated weapons and the perpetration of cyberattacks by state-sponsored and non-state terror groups call for the incorporation of the cyberspace into national security policies. The digital transformation of our industry as well as the emergence of automated—and ultimately *autonomous*—systems on the ground and in the air with new stakeholders involved in these dematerialized processes (e.g., UAS traffic management) are creating new vulnerabilities that malicious actor.[120] Digital innovation in aviation holds a lot of potential with expanded operations and new use cases, enhanced accessibility and equity, and increased efficiency and reliability. However, without security in the cyberspace, aviation will not be able to move forward without exposing the public to unacceptable risks in the real world.[121]

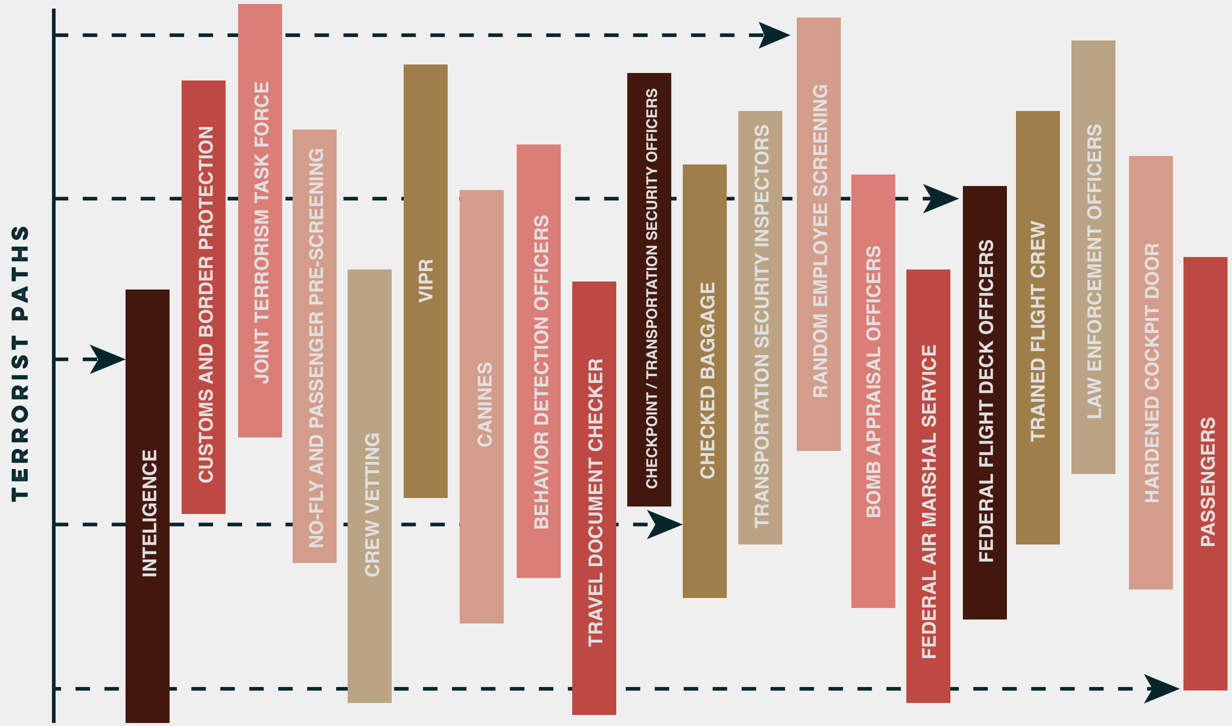
THE RISK-BASED APPROACH IS THE FUTURE

Airports are the target or the first step of most terrorist plots against civil aviation. The 1994 hijacking of the Algiers-Paris flight (AFR 8969) by the Armed Islamic Group can be seen as a prelude of the September 11 attacks perpetrated seven years later. In the period immediately following the 2001 terrorist attacks, the countries the most targeted by jihadist groups and their followers took exceptional measures to prevent aircraft hijacking and bombing. Adjusted multiple times afterwards, these standards provide an efficient security net today. Two decades later, the number of hijacking attempts has plunged, and the aviation community is now better prepared to counter in-flight attempts.[122]

As in aviation safety, the Reason model applies in security (Fig. 9). Adding layers of different measures

FIGURE 9. LAYERED SECURITY APPROACH IN THE UNITED STATES

Source: U.S. TSA



and policies reduces the likelihood of an attack to be successful. Because terrorists adapt to countermeasures and innovate as well, these security layers are versatile and evolutive. ICAO now promotes this risk-based approach. Per the Global Aviation Security Plan roadmap,[123] nations should conduct their own security risk assessment, develop a national security plan from this assessment, and then refine locally and implement at the airports.

While the post-9/11 measures intended to implement the same restrictive standards at all airports, it is now time–more than two decades after the September 11 attacks–to reassess the threat and revise standards meet to future, long-term challenges. In the United States, the TSA is designing the checkpoints of the future ("Screening at Speed").[124,125] TSA is considering introducing more preclearance levels to its TSA Pre-Check program. Processes would range from the existing full-screening methods for the noncleared passengers to a sensor-based walk-through concept with shoes and bag closed. Identification control could be expedited via biometrics. The goal of switching from a "100% screening" approach to smart and adaptive concept of operations is to increase capacity, lower operating costs, and reduce intrusion into the passenger journey.

SECURITY MANAGEMENT SYSTEMS AND SECURITY PROMOTION CAN MAKE A DIFFERENCE

Security management systems enable a systemic and systematic approach of security issues. The threat assessment that is the basis of the risk-based approach should be revised periodically and triggered by alerts from the intelligence community, security events, or geopolitical evolutions. Assessments must consider the specificities of each facility. For instance, because they are gateways to the world, hub airports are particularly exposed to security events of various levels of severity triggered by border issues and geopolitical events. International flights can be subject of specific threats. The repatriation of immigrants has caused altercations at airports with either escorted migrants or activists trying to prevent removals. In October 2023, a mob stormed Makhachkala Airport in Dagestan, Russia, to commit a pogrom against passengers from Tel Aviv. This action was incited on an antisemitic channel and triggered the Israeli-Palestinian conflict.

Education and training of the greater airport community are vital for raising awareness about security threats. Airport professionals are on the front lines and can identify suspicious activities and recognize threats. For instance, facing an active shooter event, every second counts, and the actions of each individual can save lives. Recent occurrences show that there is much to be done in this domain. A widely disseminated awareness culture could significantly help people to detect and contain non-terrorist, non-criminal security offenses, such as accidental intrusions that can degenerate into serious safety threats.

Security awareness should not be limited to annual training sessions for badge holders. Joint training between the different stakeholders of the same area of the airport should be implemented.[126,127] This outreach should include all the stakeholders potentially exposed to or able to provide early warning against terrorism and active shooters. In the aftermath of the Brussels Airport attacks, taxicab drivers in London have received training for identifying and reporting suspicious customers. At least one large hub airport in Europe involves spotters in delivering them authorization, and in return constituting a small community active along the airport perimeter that can report suspicious activities and “fake” photographers.

While the potential use of general aviation aircraft has been mentioned as a threat after the September 11 attacks, the reality is that such a tactic is not cost-efficient or effective. Using general aviation aircraft to commit acts of terrorism requires logistics including pilot training and preparing highly explosive devices as these aircraft are slow and have a limited payload. The 2009 tentative suicide strikes by the Tamil Tigers using light aircraft demonstrates the difficulty of this modus operandum. Moreover, better security awareness after September 11, reducing the likelihood of a light aircraft being hijacked without being reported.

CRIMINALITY MUST BE FOUGHT TOO

Airports are large facilities where people and goods transit and therefore, they can be subject to criminal activities. These criminal activities include the theft of baggage, unattended personal belongings, and vehicles. People who commit larcenies can be external to the airport professional community but can sometimes be employees. The number of thefts at commercial airports is highly variable, but typically ranges between 0.5 and 2 per 100,000 passengers at facilities where law enforcement is reporting these figures.[d] Automation and security systems at baggage handling systems have reduced the vulnerability of baggage handling to unlawful activities. Also, the reinforcement of security measures and the presence of law enforcement at airports after the September 11 attacks have reduced the occurrence of theft in the public area.[128]

Taxi scams are also frequent at airports. In particular, scammers target international airports because of foreign tourists unfamiliar with local operators and regulations. Passengers flying from abroad and carrying valuables are easy targets. However, mobility innovation, adequate curbside strategies, and best practices within the industry have been successful at mitigating taxi scams. The organization of taxi pickup, the rise of app-based transactions, and a better information of arriving passengers have made it harder for fake taxis to proliferate. At Paris-Charles de Gaulle, driver unions have organized red-vest squads of volunteers to provide orientation to passengers exiting the airport and looking for taxis. At most commercial airports, pickup is now extremely regulated, confined to specific portions of the curbside, sometimes limited to licensed operators with specially labeled vehicles, and ride fares to downtown or business districts are fixed or caped.

All unlawful activities at the airport do not target aviation per se, but rather use it as a vehicle for supporting organized crime operations. While Central America and the Asia-Pacific regions are major centers of

d These figures account for all thefts reported. Baggage theft is one form of property theft. It should not be confused with bag mishandling which includes all loss and damage forms filled by passengers–the large majority of them retrieving their property.

production for drugs, the nature of the products trafficked and routes operated by smugglers are changing. Western and Central Africa are now important hubs for transshipments to Western Europe and even North America. Criminal organizations are adaptive and seize short-term opportunities with, for instance, a dramatic short-term increase of smuggling from or through Venezuela as the political and economic structure of the country has collapsed. The current strategy against smuggling—a blend of police intelligence, canine patrols, profiling, and selected in-depth inspections of passengers and freight—will continue to be the most efficient with the support of technology. For instance, explosive scanners can be equipped with sensors able to detect narcotics.

According to the U.S. State Department, 600,000 to 800,000 people are trafficked across international borders every year, of which 80% are female and half are children. While there are no aviation-specific figures available, the use of air transportation for trafficking people worldwide is widely documented.[129] In 2016, the U.S. Congress made mandatory for air carriers to provide human trafficking awareness training to the cabin crews. Other countries have or are working on introducing similar legislations. Several airports have programs of human trafficking awareness, including to the public.[130]

CHAPTER 5

ENHANCING AVIATION SAFETY UNDER A GROWING AND MORE DIVERSE TRAFFIC

COLLABORATION CAN BUILD A COLLECTIVE EXPERTISE IN SAFETY AND FAST-TRACK ENHANCEMENTS

The number of fatalities per revenue passenger kilometer (RPK) flown has decreased since 1970 (Fig. 10).[131] However, this function has a logarithm-like shape, which means that it is becoming increasingly difficult with the current conception of safety to reduce fatalities as safety has improved overall. This calls for a revolution in aviation safety. Also, RPK does not consider general aviation. The number of accidents has decreased for general aviation, but specific features of general aviation safety statistics call for attention—such as a peak of fatalities around 200 hours of experience.[132] A comprehensive risk-based approach should not consider fatalities only. Incidents of lower severity can be the precursors of fatal occurrences (Fig. 11). Aviation safety shall prevent passenger and worker injuries as well as nonfatal damages to aviation assets.

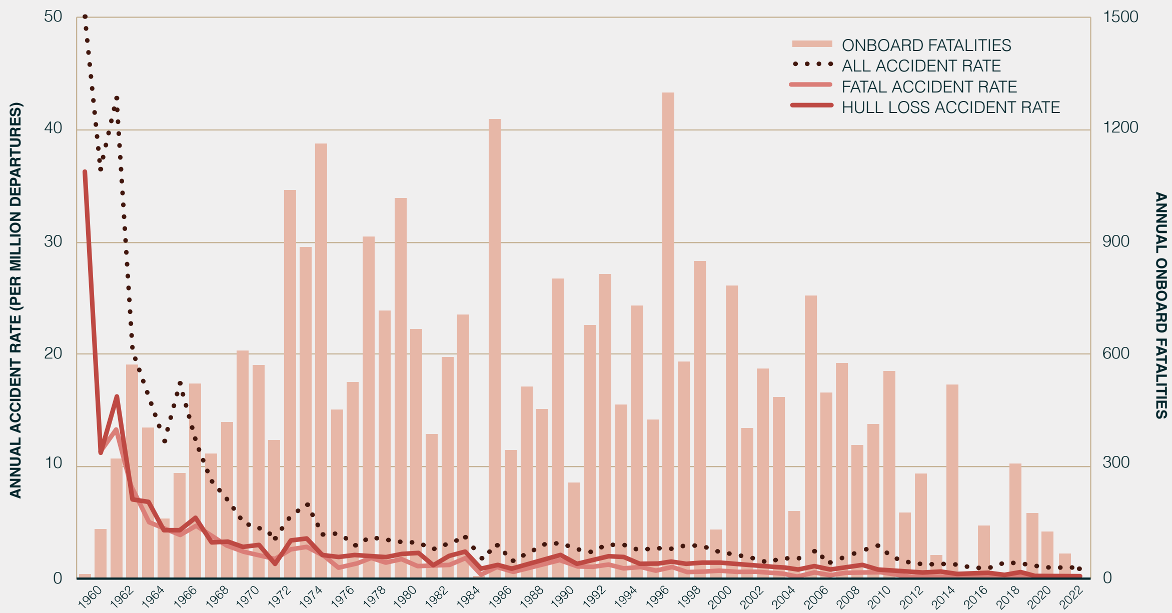
Over the second half of the 20th century, standards in airfield design were conservative and prescriptive. Progress in safety studies, bolstered by the need for accommodating larger aircraft with existing infrastructure, showed that these design standards were often overestimating risks and sometimes underestimating them.[133,134] These research efforts fostered a mutual understanding of the stakeholders of airfield design and certification, airport and flight operators, aircraft manufacturers, ANSPs, and civil aviation authorities. More importantly, they created a momentum in safety and regulations that enabled the emergence of a risk-based approach to airfield design standards, which is at the intersection between aeronautical science and civil engineering.[135,136] This new vision led to the redefinition of several design criteria and standards in the 7th and 8th editions of ICAO's Annex 14.[137]

Most of the infrastructure enhancements possible for ensuring aviation safety at airports has already been developed. "Hardware" design standards have reached an exceptional maturity. Mitigation was developed for addressing the most impactful deviations to these standards. Arresting systems provide since the late 1990s, a solution to airports lacking space for a standard Runway End Safety Areas (RESA).[138,139] A cost-efficient solution for smaller aircraft could make the case for equipping general aviation airports as well.[140,141] Another improvement of international standards could better protect people and assets on the ground against the fall of an aircraft in the vicinity of runways.[142] To date, a few countries, including the United States, require airport operators to freeze the land beyond the RESA. These areas extending up to 810 meters beyond the runway extremities for this purpose are called "runway protection zones" in U.S. standards.[143,144]

A Safety Management System (SMS) is a systemic and systematic vision of safety that the ICAO adopted in 2004.[145] While some airports are still in the process of implementation, SMS is now a well-accepted international standard that has significantly contributed to the advancement of operational safety, including on the traffic and nonmovement areas with the inclusion of ramp safety and ground handling. SMS has brought together the stakeholders of airport operations

FIGURE 10. ACCIDENT RATES AND ONBOARD FATALITIES BY YEAR FOR COMMERCIAL JET AVIATION

Source: Statistical Summary of Commercial Jet Airplane Accidents: Worldwide Operations (1959-2022), Boeing, September 2023



at individual facilities to build a joint ambition in aviation safety. Industry working groups[a] and forums[b] with an emphasis on safety have tremendously helped airports share best practices and advance safety. The TRB and Airport Cooperative Research Program (ACRP)[146] have produced a considerable amount of research studies, synthesis on practices, and guidance materials that have helped practitioners around the world. Groups of airport operators have led the way and addressed together significant operational safety challenges–some of their answers have become standards.[c]

PAVING THE WAY TO THE FUTURE OF AIRPORT AND AVIATION SAFETY

The next frontier to improve safety standards is made of real-time systems and data. Data sharing and real-time analysis of these data will increase both operational performance and safety. For example, the lack of safety data available have prevented airport safety risk analyses from being as quantitative and comprehensive as they should be. A systematic reporting of accidents and incidents and the centralization of these data help stakeholders identify trends and assess the impact of changes in the aviation operating environment. At the level of individual airports, collecting and analyzing occurrences is vital for understanding the state of safety. Efforts to collect information should involve all parties involved, with airside operations including the ramp that is not systematically integrated into these processes and where practices can vary from an operator to another.[147,148]

Sharing data and other information between operators can raise

a Such as the Technical, Operations & and Safety Committee (TOSC) of ACI Europe, the Infrastructure Workgroup of The French-Speaking Airports (UAF&FA), and the Airport Construction Advisory Council (ACAC) of the FAA.

b Recent national and regional events include the AAAE/FAA Airfield Safety, Sign Systems and Maintenance Management Workshop (United States), Eurocontrol Airport Surface Risk Safety Forum 2020 (Belgium), 2019 ANAC Fórum Técnico de Obras (Brazil), and 2017 DSAC Symposium on Runway Construction Safety (France).

c See Appendix E: Enhancing Aviation Safety During Airport Construction.

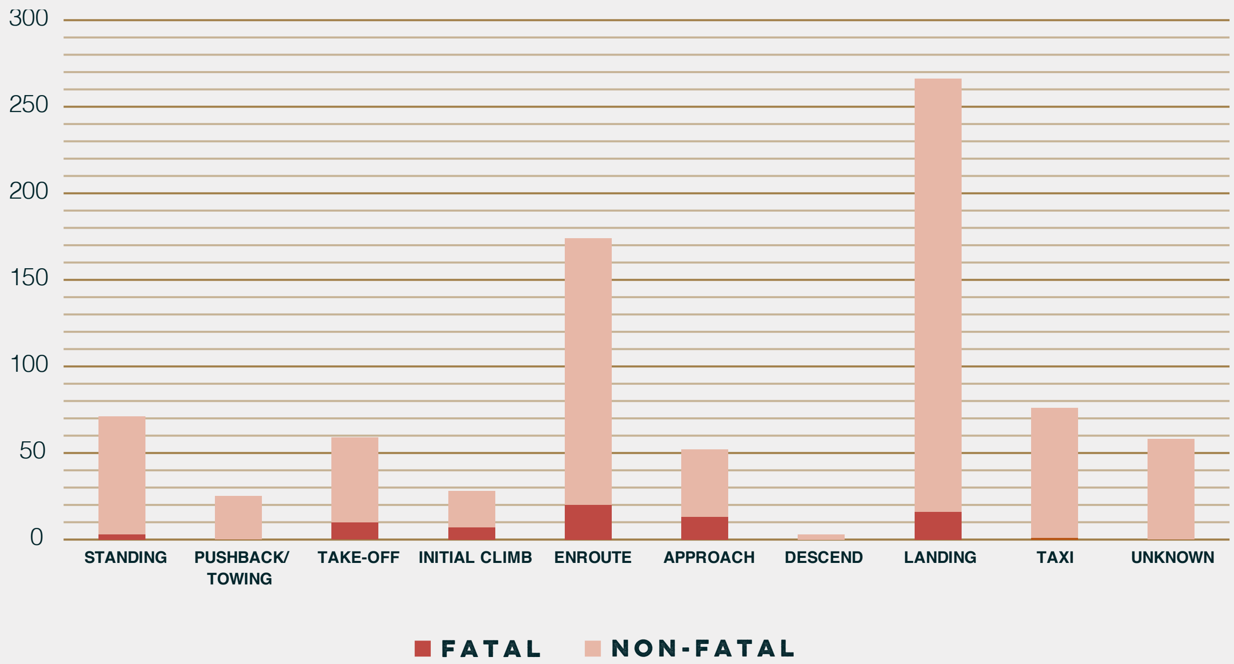


FIGURE 11. ACCIDENTS PER PHASE OF FLIGHT FROM 2013 TO 2022

Source: ICAO iSTARS API Data Service, October 2023

awareness on issues that may be underrepresented in local statistics or absent from some airports. At the national level, this sharing provides national aviation authorities with the right tools to get a detailed vision of safety issues—a condition for designing an efficient State Safety Program (SSP).[149] Furthermore, data science applied to big data from aviation operations can provide advanced analytics to discover new safety issues, determine potential precursors holistically, even perform predictive safety (Fig. 12). An example is the Aviation Safety Information Analysis and Sharing initiative in the United States. This initiative is a collaboration between the FAA and the aviation community. The MITRE Corporation collects, safeguards, aggregates, and analyses data sets from the FAA, public sources, as well as air carriers and manufacturers.[150]

Sensors available can now provide an estimate of the surface condition of runways. Radar and visual systems detecting foreign object debris are now available to tackle an issue that has not yet been fully addressed in the field nearly 25 years after the crash of Concorde at the Paris Charles de Gaulle Airport.[151,152,153] The Autonomous Runway Incursion Warning System[154] such as the Runway Status Light[155] provides visual information on runway occupancy to the crew, preventing runway collisions. More cost-effective technologies for runway incursion prevention on the ground are being developed in the United States through the Runway Incursion Reduction Program.[156]

The next innovations may not rely on physical, ground-based equipment. The future of airside safety also resides in cockpit equipment, such as runway incursion prevention systems, aircraft-ground data exchange, and the use of big data and artificial intelligence in real-time.[157] Several cockpits already navigate airfields with the assistance of dynamic digital aerodrome charts. With inflight updates, these charts could include the latest aeronautical information published by airports, provide enhanced guidance information during taxiing, and raise awareness and generate alerts on airfield safety issues such as runway incursions and wingspan restrictions.[158]

Runway adherence is an essential information for preventing runway

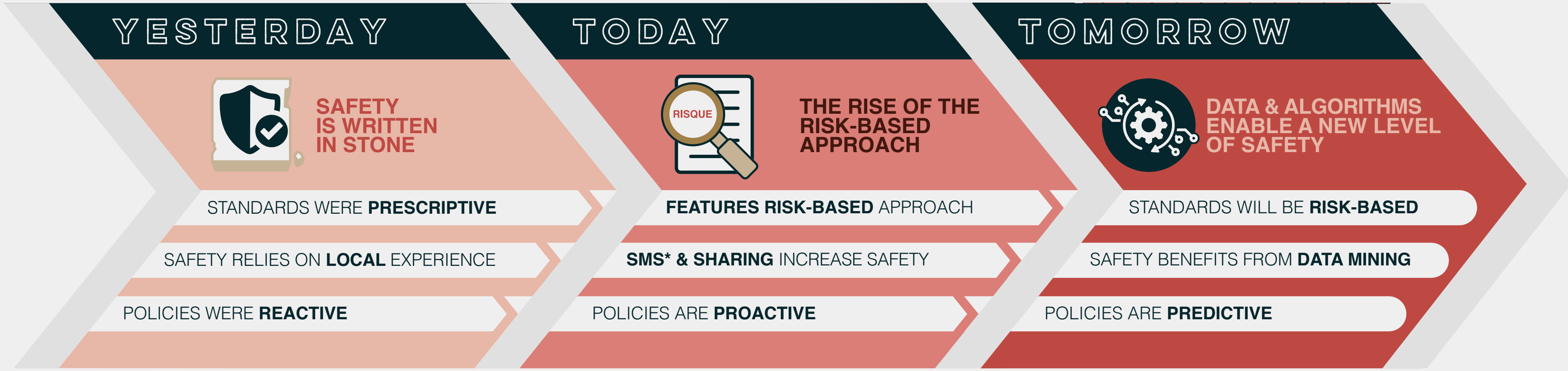


FIGURE 12. LONG-TERM TRENDS IN AVIATION SAFETY

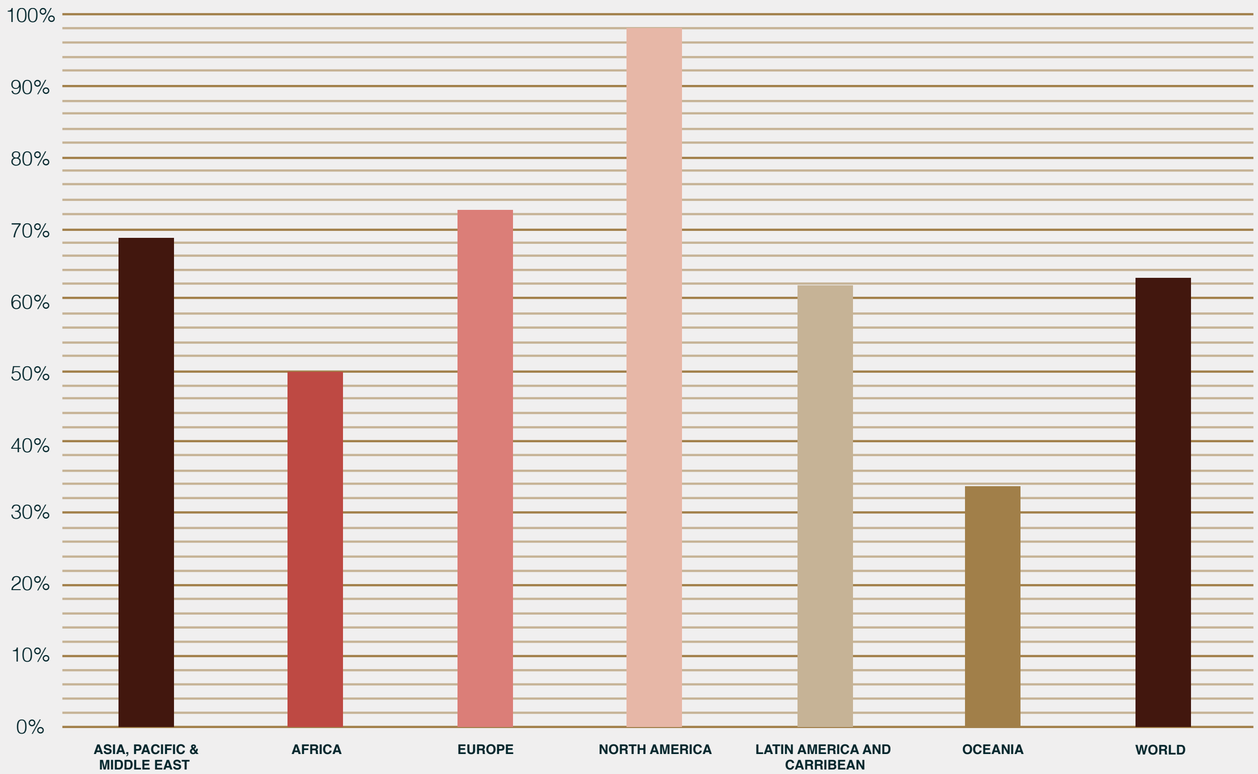
excursions and triggering runway deicing and snow removal.[159] Airbus[160] and Boeing[161] both developed onboard Runway Overrun Awareness and Alerting System. Next, these systems could exchange their assessment of the friction coefficient with other aircraft and the ground, providing a real-time, reliable, and aircraft-centered measurement of this value in a complement of the estimate derived from heterogeneous methods currently in use around the world.[162,163] Combined with AI, this information could assist airports in their decision-making for continuing operations under rainstorm or winter conditions, triggering rubber removal and winter operations, and for enhancing airline procedures and individual pilot safety performance.

The emergence of advanced air mobility (AAM) enabled by a new generation of electric aerial vehicles and other aerial innovations has raised questions regarding the safety of these operations. The experience in early forms of UAM over cities such as São Paulo, Brazil, demonstrates that it can be safe with today's helicopters with specific flight procedures. However, the intensification of vertical take-off and landing operations, the extension of the domain of operations to IMC, the introduction of new players and vehicles, and the coexistence of piloted, remotely piloted and autonomous vehicles in the lower airspace call for new concepts of operations and standards. The ongoing research efforts in UAS and UAM traffic management aim at addressing these issues and enabling a safe and efficient deployment of UAM. The innovation being developed for AAM, such as the In-time Aviation Safety Management System concept, could ultimately advance safety in order operating domains.[164]

Concepts and technologies developed for AAM and remote tower centers could contribute to the improvement of safety at "conventional" ATC facilities. At the 2040 and 2070 horizons, the stakeholders of real-time airfield and airspace operations will have more tools assisting them in the decision-making tasks and providing predictive scenarios during adverse conditions. In the future, the complexity of some concepts of operations might take part of the human decision out of the loop. This transition toward more

FIGURE 13. USAOP EFFECTIVE IMPLEMENTATION ON AERODROME AND GROUND AIDS

Source: ICAO iSTARS API Data Service, October 2023



automation in critical tasks and safety nets will require a careful assessment of the potential adverse impacts, and contingency plans in case these systems fail.

AVIATION SAFETY IN THE EMERGING WORLD MUST IMPROVE NOW

According to International Air Transport Association, China has now surpassed the United States to become the world's largest aviation market. Thailand should make the top 10 by 2030. By 2040, India and Indonesia should be among the five largest markets. In the meantime, Africa is the fastest-growing region with a compound annual growth rate of 4.6%. Latin American and Caribbean will follow closely with a compound annual growth rate of 3.6%. As air traffic should dramatically increase in the newly industrialized and developing world over the coming decades, countries with fewer safety regulations must keep up with the rest of the world. Their unpreceded growth is synonymous with an urgent and large need for aviation professionals. In an industry where experience and mentoring can make a difference, an influx of young professionals on critical positions of all the components of the local air transportation system can threaten safety.

It is vital to acknowledge that the level of safety is not the same throughout the world. Airports and oversight authorities shall work at closing the gap on ICAO standards. They should be inspired by the recommended practices as well to champion safety. Moreover, they shall become aware of their local specificities and gaps, and work on addressing them timely. The ICAO Global Aviation Safety Plan (GASP) is calling for such effort worldwide. The previous plan fell short in bringing all states up to the target on effective oversight implementation by 2017.[165,166] The ongoing plan aims at getting each country to define and implement an SSP.[167] The next period to the 2028 horizon focuses on implementing advanced safety oversight systems, including predictive risk management—a step that the most advanced countries have already achieved.

The Universal Safety Oversight Audit Programme (USOAP)[d] revealed that the average global effective implementation of ICAO's standards and recommended practices with regard to aerodromes is of 62% as of 2024 (Fig. 13). Considering the items at stake, this is poor performance–and it is one of the lowest implementation rates of all the USOAP domains. Airports and the other stakeholders of flight operations need strong national aviation authorities to support national industries and ensure the safety of the overall air transportation ecosystem. In less performant regions, a safety revolution is needed to safeguard passengers and aviation assets. Beyond compliance with ICAO standards on oversight, each segment of the air transportation system must comply with international standards and best practices, and a safety culture must develop inside the aviation community, from the field to the executive management and governments. As these countries are at the threshold of unprecedented growths of air transportation, their governments must realize the imperative need for safety and pave the way to a bright and safe future for their aviation and airport industry.

Achieving this requires specific progress in the funding, governance, and continuous improvement of aviation safety.[168] First, governments must provide the national aviation authorities with adequate financial means and workforce, organic and effective independence, and a strong commitment to "safety first." The partial delegation of monitoring and certification to the operators cannot be a solution to organic deficiencies of the national aviation authorities. Then, major deviations to airport standards should be removed. Airport operators cannot be expected to undertake alone all corrective actions. Grading runway strips, creating RESA, removing obstacles and moving habitations, installing airside fencing, procuring rescue and firefighting apparatus, and wildlife mitigation equipment might call in some cases for governmental coordination and public funding.[e] Adequate land use planning and strict enforcement of good sense rules can prevent the errors of the past from being repeated. In some cases, international institutions such as the World Bank, ICAO, and other assistance mechanisms can provide funding to infrastructure projects and studies. The support of the ICAO is also offered as part of the No Country Left Behind initiative.

Beyond the needs in infrastructure and equipment, a strong airport safety culture shall emerge within the airport staff and among the stakeholders. It should take into consideration the human and organizational aspects of safety. It must be supported by the top management, embraced by the field, enable bottom-up reporting, and include the stakeholders as well. It means providing adequate means and training to the acting staff, and ultimately implementing SMS. It also means fostering a safety culture based on transparency, non-punitive reporting, lessons learned, and risk management.

d USOAP audits focus on validating a State's capability of performing safety oversight of its industry.

e This applies to developed countries as well. In the United States, RESA and arresting beds (EMAS) were implemented with the help of the Airport Improvement Program (AIP) and coordinated by the FAA through the Runway Safety Program.

A great deal can be achieved with co-operation within the airport community in each country, with the national aviation authorities, and through international cooperation as well. Making the information accessible to the industry is a must-do, and while internet accessibility is now widespread, too many countries—including developed nations—do not provide safety regulations and practices on their websites. Sharing accident and incident databases with the industry to make this knowledge available to practitioners and facilitate the lessons learned process is critical. National or local symposiums and safety task forces or action teams can help tackle the top priorities. Learning from others, gathering external lessons learned, and implementing best practices is a way to fast-track safety enhancement. High-level regional meetings at the governmental or industry levels are not enough and do not address alone the safety challenges ahead. Direct cooperation between airports, workshop between field operations teams, transnational collaborative work on specific issues, and dissemination of industry best practices may provide the complement to fill the gap.

CHAPTER 6

AIRPORT COMPATIBILITY: ACCOMMODATING THE NEXT GENERATION OF AIRCRAFT TECHNOLOGIES

DIVERSITY IS IN THE AIR

Airside and airspace are going to experience more diversity in the next coming decades with new aircraft configurations, aviation technologies, and applications. The lower airspace will become busier. Advanced air mobility promises a new era of flight with innovative aerial vehicles. Most of the aircraft under development for AAM have vertical or short takeoff and landing (VTOL/STOL) capabilities. They should be safer, cheaper, quieter, and greener than comparable small aircraft with conventional features. Upon being certified by the regulators, they will carry passengers and freight on short intra- and inter-urban trips. One of the key markets is UAM in dense metropolitan areas that are struggling with acute congestion UAM. UAM will be provided by electric vertical takeoff and landing (eVTOL) aircraft moving two to six passengers or light freight. Use cases include on-demand air taxi by crewed vehicles (at least at first) as well as parcels and cargo deliveries with UAS (Fig. 14).[169]

With their very low disk loading and high performance, helicopters will still be machines of choice for missions involving heavier payloads, longer range, and prolonged hovering periods (e.g., aerial crane and search-and-rescue). High-speed rotorcraft equipped with propulsive engines (e.g., tiltrotors and compound helicopters) will target market segments where speed and endurance matter. Although they will occupy a small portion of the civilian rotorcraft market, they could be of interest for applications such as air ambulances, high-value flights, law enforcement, military missions, and offshore services. AgustaWestland has developed the first civilian tiltrotor vehicle. Airbus[170,171] and Sikorsky[172] have flown demonstrators of high-speed helicopters.

Electric aircraft is a broad category of aerial vehicles which includes eVTOLs but also fixed-wing horizontal takeoff and landing aircraft powered by electric and hybrid propulsions systems (EHPS).[173] The first commuter aircraft retrofitted with an electric engine flew in December 2019.[174] Besides vehicles developed for AAM, EHPS have potential for powering general aviation, commuter services, and regional aviation. These applications might become a commercial reality by the end of the 2020 decade. The feasibility of powering larger mainline airliners with electric engines only in the foreseeable future is not yet clearly established. Instead, larger aircraft might have hybridized gas turbine engines electrically assisted during part of the flight for lowering consumption.[175,176] More electric aircraft could also use fuel cells or batteries to specifically power nonpropulsive needs and relieve the engines from that task.[177,178]

The regional aviation market is calling for a new generation of highly cost-efficient 50- to 75-seat aircraft.[179] While small regional jets such as the CRJ series and the ERJ-145 will be operated for many years, the time of their retirement is on the medium-term horizon and some air carriers are actually phasing them out entirely.[180] The Q-Series, ATR family, and MA60/600 are among the few turboprop regional aircraft in production today. All of them derive from aircraft designed in the mid-1980s. Future turboprop models could integrate electric and hybrid propulsion systems as well as hydrogen.

Older and smaller narrowbody aircraft are being replaced by fuel-efficient jets of more advanced design. With the Airbus A220 and Embraer E-Jet E2, the distinction between regional and mainline airliners has become thinner. Also, larger medium-size aircraft are now being used on long-haul flights and open new opportunities for direct service from small and medium hub airports. The A321XLR will soon be flying routes formerly reserved to middle-of-the-market Code D aircraft (Boeing 757 & 767). These trends mean that terminal facilities and aprons shall be more versatile than before and be compatible with a more diverse fleet.[a]

The termination of the production of the A380-800 was not the end of the large aircraft era. First, the Airbus A380 and Boeing 747-8 will still be flying until at least the 2040 horizon. Then, the next generation of large and long aircraft is already being delivered with the A350-1000 and 777-9. The growth of the worldwide population, the emergence of new megalopolis with a strong middle class, and the scarcity of airside/airspace capacity make the case for the "jumbo" aircraft.

Supersonic aircraft will likely be back in the air by 2040. Nearly 20 years after the last flight of Concorde, and after the cancellation of many other projects, the Boom Overture is the only active commercial aircraft under development on this market segment with a projected entry into service around 2030. On the research side, the NASA/Lockheed Martin X-59 Quiet SuperSonic Technology) has made its roll out and is now poised to start flying in 2024 to explore low-boom design.[181] However, flying over Mach 2 burns over three times more fuel than a subsonic cruise.[182] Their impact on climate—especially on atmospheric composition at higher altitude—is still uncertain.[183] If supersonic airliners succeed in becoming a commercial reality again, standards will be needed to regulate their emissions and noise.[b] The comeback of supersonic flights should not hinder the effort made by aviation to reduce its environmental footprint.[184]

A hypersonic civilian market could emerge beyond 2040. The idea of using hypersonic aircraft, gliders, or rockets for long-range transportation is not new and was first proposed at the end of World War II.[185] The development of new technologies, materials, and manufacturing processes could make them available to civil aviation for commercial services or corporate aviation.[186] Firms such as Destinus, Hermeus, Reaction Engines, and Venus aim to make hypersonic passenger flight come true. SpaceX has suggested that its reusable Starship under development could be used for intercontinental routes.

Other types of vehicles are emerging or reemerging. The few dirigible airships in operation are currently providing advertising, sightseeing, surveillance, and research. New models, some of them electric and uncrewed, are being developed for serving also as aerial cranes, freighters, and emergency relief platforms.[187,188] They may also provide high-altitude platform systems along with high-altitude, long-endurance airplanes. Finally, seaplanes and wing-in-ground effect vehicles or "seagliders" are experiencing a revival as well with projects aiming at the coastal, inter-island, and offshore markets.[189] Interestingly, the latter might be certified as vessels rather than aircraft.[190,191] If all these

a See Appendices F and G.

b Supersonic airliners are not currently covered by the aircraft noise standards of ICAO's Annex 16.

FIGURE 14. RENDERING OF THE PROPOSED PIPISTREL NUUVA V300 DURING CARGO LOADING

Source: Textron eAviation/Pipistrel Aircraft (2024)

vehicles will only account for a small portion of aviation in the future, they will interact with the rest of the traffic and will need a ground infrastructure for supporting their operations.

SHORT- AND MEDIUM-TERM AIRCRAFT EVOLUTIONS

Many historic airports started their operations with transport aircraft such as the Bloch MB.220, Douglas DC3 or Junkers Ju 52 which were small in size compared to today's airliners. In the immediate post-war period, the rapid growth of air traffic justified the introduction of aircraft with ever greater capacity and range. The turbojet was a major revolution that determined a limited number of efficient aircraft configurations that have endured until the present day. Under these conditions, the size of aircraft has steadily increased throughout the history of commercial aviation to improve payload, fuel load, and fuel efficiency.[192] Therefore, airports had to learn how to develop their own technical policies as well to ensure safe and efficient operations.[193,194]

The emergence of the New Large and Long Aircraft in the 1990s and 2000s—the A340-600, A380-800, 777-300/-300ER, and 747-8—compelled airside stakeholders to work together for fitting these aircraft at existing airports. The aviation community conducted research and achieved consensus for safely accommodating large aircraft at aviation facilities that were not initially designed for them. Guidance documents were issued for the A380-800, 747-8, and 777-8/-9.[195,196,197] Moreover, this effort led the introduction of the risk-based approach in airport design and operations, and to a remarkable work for preparing Amendments 13A and 14 to the Annex 14 of the Chicago Convention. Airport design criteria were reviewed, safety objectives were clarified, and standards and recommendations were redefined based on science. Today, mature methodologies and models are available for developing aeronautical studies supporting local modifications of standards on runway width, instrument landing system protection areas, taxiways, and other criteria when the prescribed values cannot be reasonably achieved.[198,199,200,201]

The latest generation of long-haul aircraft such as the Airbus A350-900/-1000 and the Boeing 777-8/-9 are more demanding than their predecessors on many airport compatibility aspects such as the aircraft stand depth, taxiway fillets, and pavement bearing strength. The 777-9 is the longest commercial aircraft ever (Fig. 15), and a longer version has even been considered (777-10X). There is an upward trend in the tire pressure of aircraft–meaning that more weight is getting concentrated on a smaller area. Freighter variants of these large aircraft (A350F, 747-8F, 777-8F) are being commercialized as they can support the busiest routes.[c] Domestic facilities also see similar trends with longer and heavier narrowbody aircraft for serving existing destinations. Aircraft compatibility under an evolving fleet mix is a challenge for airports of all sizes. Compatibility issues can have an impact on air service development, certification, asset management, and capital expenditure. Careful planning is vital to integrate provisions for future needs and mitigate cost for adapting infrastructure and equipment to more demanding aircraft.

Aprons are also concerned with air-port/aircraft compatibility. For the short- and medium-term horizons, airports will have to continue adapting their ramp infrastructure to fit new airframes of different shapes with potential challenges with aircraft stand depth, fuel pit location, and jet bridge compatibility. Electric and hybrid propulsion systems for regional aircraft and mainline airliners might require airports to install powerful charging stations at the gate. Novel electric VTOL aircraft might start commercial operations as soon as 2025. Regional electric and hybrid aircraft could follow closely. Ground service equipment (GSE) vehicles also turning electric. As of today, virtually all GSE vehicles have electric counterparts in the catalog of the main manufacturers–including tow-tractors. These vehicles need charging stations, further increasing the power demand. These changes are happening in the broader context of an unprecedented "Electrification of Everything" at airports inaugurated with the transition from auxiliary and diesel ground power units to 400 Hz power units connected to the grid or relying on batteries.

Cost-efficient airport operations strategy from airlines have also reshaped terminals and aprons. Ultra low-cost carriers prefer simplified facilities and procedures to cut the turnaround time to the minimum. For instance, the walk-in/walk-out process generally involve boarding and disembarking passengers through the front and rear aircraft doors simultaneously with mobile stairways or ramps and walking them to the terminal. This requires provisions for safe and efficient operations including adequate markings, separations, equipment, and staffing. An emerging trend with legacy carriers is a niche but growing number of short-haul secondary routes being operated with motorcoach buses in North America—maintaining air service and regional air connectivity. The ticketing and airport operations are integrated with those of the air carrier contracting the service enabling passengers to board and deplane airside (at the gate).[202]

Another recent change is the introduction of sustainable taxi operations. In addition to single-engine taxiing, two types of lower-carbon emitting

c See Appendix H: Cargo Volume Payload of Commercial Freighters.

FIGURE 15. BOEING 777-9 WITH FOLDING WINGTIPS UP

Source: Boeing (2020)

solutions have been developed: on-board electric engines driving the landing gear (e.g., WheelTug) and external (ground) equipment towing the aircraft from the gate to the threshold (e.g., TaxiBOT at Frankfurt Airport and Delhi–Indira Gandhi International Airport).[203] The success of such equipment has been mainly subject to the price of kerosene. However, the long-term increase in fuel price, the social pressure to get greener, and technical progress (e.g., reversible electric brakes) might accelerate adoption.

2035 AND BEYOND: IMPLEMENTING BREAKTHROUGH AIRCRAFT INNOVATIONS

A revolution in aircraft configuration is on the horizon. The general geometry of aircraft has not radically changed since the Boeing 707 and the Douglas DC8. New fuel-efficient, noise-friendly configurations have been studied by manufacturers and the aerospace research community for decades. Part of this research has been supported by public funding (e.g., EU Clean Sky, NASA Advanced Air Vehicles Program) to pave the way for the next generation of airliners that will replace aircraft such as the A320 and 737 families.[204,205] Convergent statements from commercial aircraft manufacturers suggest new programs integrating these innovations should materialize around 2035.[206,207,208,209,210,211,212] These innovations are not likely to impact the airport setting the same way. It is important that the aircraft/airport compatibility aspects are taken into consideration when developing and implementing new aircraft features.[d] The viability of future aircraft programs and the successful transition of aviation toward a more sustainable future are at stake. Future aircraft programs cannot be successful if they warrant extensive modifications of the airport infrastructure worldwide.[213]

An example of a breakthrough innovation is the high-aspect ratio wings. This wing geometry achieves fuel savings through a reduction in lift-induced drag.[214] For an aircraft of given speed and wing area, this drag is proportional to the inverse of the wingspan. By increasing the latter, it is therefore possible to reduce the energy required to move the aircraft

d See Appendices J and K.

forward. The principle was put into practice in 1948 by French engineer Maurice Hurel, with truss-braced wings.[215] NASA explored this configuration in the late 1990s as part of studies on future airliners. In January 2023, as part of its Sustainable Flight Demonstrator program, the agency announced $425 million in aid to Boeing to develop the X-66A, an «X-Plane» that is expected to fly by 2028 (Fig. 16).[216]

FIGURE 16. RENDERING OF THE NSA/ BOEING X-66A DEMONSTRATOR WITH HIGH-ASPECT RATIO AND TRANSONIC TRUSS-BRACED WINGS

Source: NASA/ Boeing (2023)

A narrowbody aircraft adopting such a wing should show similar performance to current narrowbody aircraft of the same capacity with a fuel (and emission) saving of 8% to 10%. However, its wingspan is expected to reach nearly 52 meters (171 feet). Therefore, it would be an aircraft whose mission and payload are comparable to those of the Airbus A320neo or the Boeing 737 MAX (ICAO Code C) with a wing as wide as that of a Boeing 767-400 (Code D).[217] This increase in wingspan for a given class of aircraft would be unprecedented, and much more impactful than the introduction of winglets and other sharklets that added a few meters of wingspan to narrowbody aircraft in the 1990s and 2010s.

However, progress in actuators and manufacturing have made wing folding compatible with civilian aircraft. The Boeing 777-9 is the first airliner to feature «folding wingtips» to reduce its wingspan down to that of a 777-300ER (Code E) on taxiways.[e] Without such devices, high-aspect ratio wing aircraft cannot become the backbone of commercial fleets without major and extremely costly transformations of the airport infrastructure. In particular, terminal facilities and aprons would have to be significantly lengthened to accommodate the same passenger traffic, which would go against the tide of history as airports are expected to be always savvier and reduce their environmental footprint–including in the literal sense with regard to their impervious surface.

Blended wing bodies also known as “flying wings” are another configuration being considered for future civilian aircraft. In the United States, JetZero

e Another feature that could be associated with higher-aspect ratio wings are semi-aeroelastic hinges (SAHs) which are free wingtips that could also be potentially equipped with folding wing systems.

is receiving $235 million in support from the U.S. Air Force to develop a demonstrator by 2027 that could lead to an operational tanker and cargo aircraft.[218] The startup makes no secret of its ambitions to offer a passenger version that could carry up to 250 passengers (Fig. 17).[219] This Z-5 version would have a wingspan comparable to that of an Airbus A330 for a length a third shorter than a Boeing 767.[220] It could achieve a fuel consumption reduction of 50% compared to a conventional middle-of-the-market airliner. As with other aircraft projects adopting a flying wing configuration (e.g., Airbus ZEROe), the engines would be located above the wing. This feature has the potential to reduce perceived ground noise–another important element of airport compatibility.[221]

The next clean-sheet aircraft programs might also include innovative propulsion systems. Engine manufacturers are developing ultra-high bypass-ratio (UHBR) turbofans (Rolls-Royce UltraFan) and open rotor (or propfan) engines (CFM RISE).[f] Propfans may reduce fuel consumption and emissions by 10% to 20% when compared to the latest comparable turbofans (e.g., CFM LEAP), and by 5% compared to future (2037) UHBR turbofans.[222] These very-large-diameter engines, whose counter-rotating fans are unducted, are more fuel-efficient but potentially noisier than equivalent turbofans. However, ongoing research show that it is possible to reduce noise levels to ICAO Chapter 14 levels. Electric and hybrid propulsion systems will start equipping small aircraft before 2030 before being scaled up to regional aircraft and larger.[223] The next evolution of the ATR products should be hybrid-electric.[224] Other Original Equipment Manufacturers (OEMs) such as Eviation, Heart Aerospace, magniX, Universal Hydrogen, Whisper Aero, Wright Electric, and ZeroAvia are developing aircraft and systems for making fully electric conventional take-off and landing (eCTOL) aircraft a reality. These novel propulsion systems and energy sources will have implications for crashworthiness, flight control, jet blast, and ramp operations warranting a specific assessment of their operational safety impacts.[225]

FIGURE 17. RENDERING OF THE PROPOSED JETZERO Z-5 AT THE GATE

Source: JetZero (2023)

f Propfans were also considered by Boeing in the 1980s with the 7J7 project.

ADVANCED AIR MOBILITY AND THE FUTURE OF VERTICAL FLIGHT

Early forms of UAM exist in few large metropolitan areas and demonstrate the feasibility of such service. Downtown São Paulo, Brazil, is home for over 200 helicopter facilities, and it accommodates over 400,000 helicopter operations per year with specific flight procedures. This transportation system has remarkable safety records. However, noise and equity concerns have limited or reduced urban helicopter flights over several cities (e.g., New York City and Paris). New eVTOL aircraft promise significantly lower noise level, improved flight safety, increased availability, and reduced operating costs. Legacy origin equipment manufacturers (e.g., Airbus, Bell, Embraer, Textron) and startups (e.g., Archer, EHang, Joby, Volocopter) have developed over 100 concepts and over a dozen of flying demonstrators and prototypes exploring a broad diversity of configurations delivering different performance and capabilities.[226,227] Along with potential flight operators and mobility providers, they have created a thriving industry community.[228,229] To become a reality, they now need to establish safe and efficient concepts of operations, work with the civil aviation authorities to translate them into regulations, create an efficient and sustainable infrastructure, get their aircraft certified, and then find a viable business model out of these constraints. Following a "crawl-walk-run" approach, eVTOLs might be crewed at first and operate existing visual flight rules helicopter routes (2025-2028).[230,231,232,233] The ultimate goal is to move toward autonomous flight, novel air traffic management concepts, and innovative business models (2035+).[234]

UAM and UAS traffic management (UTM or U-space) concepts of operations (ConOps) explore concepts for enabling the safe operations of UAS and crewed vehicles in the lower and uncontrolled airspace.[235,236237,238,239] Allowing the operations of remotely piloted and autonomous aircraft beyond BVLOS will require these vehicles to broadcast their position in real-time, operate within authorized portions of airspace, and ensure adequate separation with other users and obstacles. The proliferation of sUAS calls for remote identification,[240,241] geofencing around airports,[242] and the separation with manned aircraft within the shared airspace. AAM corridors reserved to aerial vehicles meeting certain requirements could be activated on-demand to provide such level of safety in the lower airspace (below 1,000 feet above ground level) with third-party service providers (rather than ANSPs) supporting this new type of air traffic management.[243] The future of artificial intelligence for the command and control of these vehicles will require safe concepts of operations as well.[244]

Vertiports, vertipads, and vertistops are comparable to today's heliports, helipads and helistops in terms of complexity and capacity. However, UAM targets higher-intensity operations while helicopter facilities usually accommodate a low level of traffic. Also, vertiports will provide a broader range of services including powerful fast chargers.[245] Such equipment will be needed to recharge early eVTOLs that will have a very short endurance due to existing battery limitations. As UAM intends to provide point-to-point mobility service, it will need to access conventional airports, leverage existing heliport facilities, and create new vertiports on existing city real estate. These facilities should be planned and designed for accommodating VTOL categories and meet the needs of the market they serve rather than specific models (Fig. 18). Categorization shall keep in mind that the dawn of eVTOL aircraft is not the dusk of helicopters. These vehicles offer different capabilities and will keep coexisting.[246] In the future, larger transport VTOL projects could even gain a new momentum, benefiting from progress made through the experience of smaller vehicles (AW609, V-280), public research programs (NGCTR), and military programs (HSVTOL, SPRINT). Ultimately, the vertical flight community, including regulators, shall develop an integrated approach of compatibility across VTOL aircraft and facilities. Also, they need to develop standards and procedures to address novel hazards and ensure operational safety.[247,248] There is a need to plan for and coordinate the introduction of these aircraft and related services across the stakeholders. It is time to revive the type of aircraft/airport compatibility working groups that were setup for large aircraft under the umbrella of industry organizations such as ACI World.

Many airports already accommodate a low-intensity helicopter traffic that can be fairly easily managed. If UAM emerges quickly and provides first and last miles to commercial airports with higher intensity (dozens of flights per hour), provisions shall be taken to preserve airside capacity for accommodating eVTOLs without prejudice for the existing users. Electric VTOL aircraft have different operational requirements than conventional helicopters. For instance, they cannot hover for a long time to let the fixed-wing traffic go. Creating "landside" vertiports away from the main airport's airside and developing specific procedures harnessing the specific flight performance of eVTOLs can provide for both activities.[249] Also, providing elongated Final Approach and Takeoff Areas (FATOs) might help these vehicles save precious battery or fuel-cell energy and benefit from their unique capabilities–especially with V/STOLs. In fact, some OEMs are developing eSTOL aircraft needing no more than 90 meters (300 feet) to take off and land.[g]

Vertiports that are not specifically serving larger airports will need to be connected to ground transportation networks in order to address the first and last miles. Mobility-as-a-Service (MaaS) can provide an integrated solution for a door-to-door experience. A new ecosystem of stakeholders and skilled workers will be needed. Few metropolitan areas have an adequate network of heliports. Their development in new cities will require consequent investments and time–including environmental studies and community buy-in. Adequate procedures and navigational aids shall be provided for enabling operations during instrument meteorological conditions which are needed in order to provide a reliable service and make these aircraft more profitable. These requirements raise the question of the ownership and funding of the facilities. OEMs, legacy fixed-base operators, and private airport companies are already stepping in.

BECOMING GATEWAYS TOWARD THE SOUND BARRIER AND THE KÁRMÁN LINE

Supersonic airliners typically have a higher approach speed than subsonic aircraft. The experience of Concorde and military-civilian joint-use facilities show that it is possible to have these

g This is less than the takeoff distance of many heavy helicopters when operating under the performance class 1.

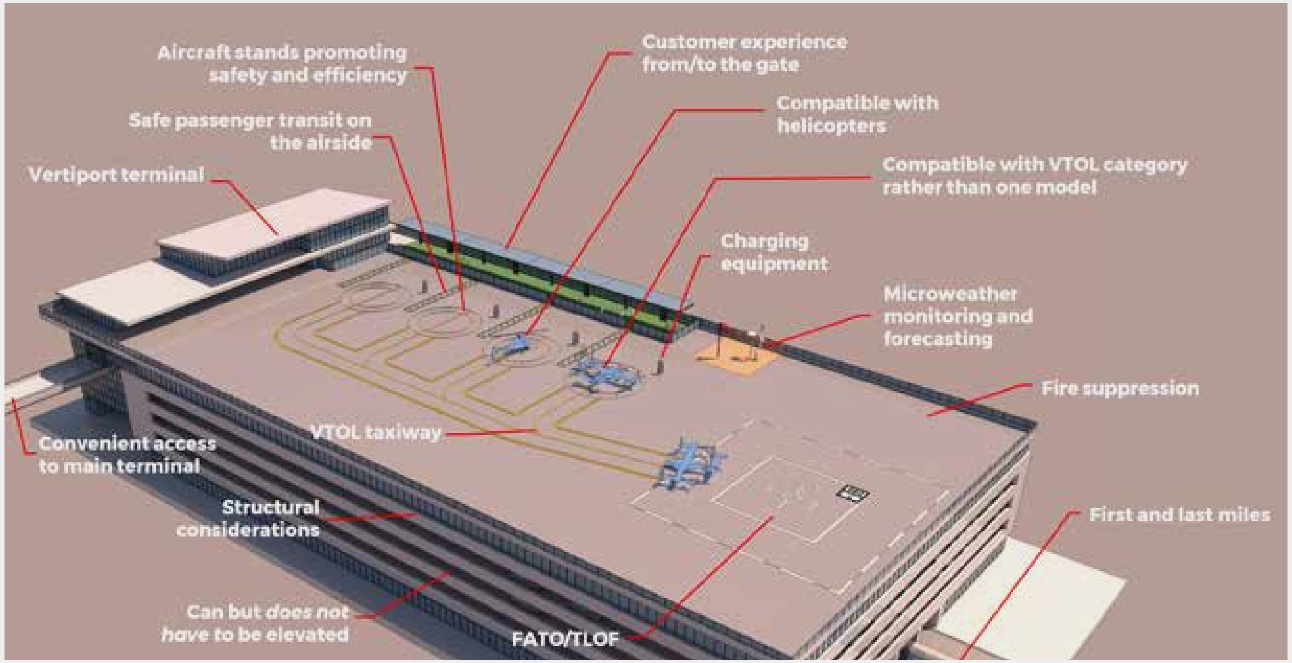


FIGURE 18. MAIN VERTIPORT FEATURES

Source: WSP (2023)

aircraft coexisting together. However, accommodating aircraft with different flight performances have an impact on the throughput. they will have longer runway length requirements which might limit airfield options, especially for potential future supersonic business jets operating from secondary airports. Supersonic aircraft are significantly longer for the same number of passengers, meaning that supersonic airliners might have to be parked on stands designed for widebody aircraft. Finally, the new generation of supersonic aircraft (Fig. 20) will have to minimize their noise and emissions to at least the levels achieved by existing subsonic airliners.[250,251] Ongoing projects typically target a ground noise lower than 75 EPN decibels (dB).[h]

Commercial aircraft already share the airspace with spacecraft. The avoidance of large aviation hazard areas around spacecraft launches and reentries by commercial flights during several hours causes significant delays when they are activated. The growth of commercial space transportation with new spaceports and spacecraft operators requires rethinking how these users share the resource. There are currently 14 licensed spaceports in the United States[252] that has a comprehensive regulatory framework for launch[253] and reentry[254] site operator licensing. Six of them are active general aviation airports. Some are in the immediate vicinity of hub airports such as the newest U.S. spaceport, Colorado Air and Space Port, is situated at less than 5 NM from Denver International Airport. The FAA has rolled out new tools for a more dynamic allocation of the airspace resource such as the Space Data Integrator (SDI).[255] ADS-B is being tested on rockets. The emerging Space Traffic Management will have to interface with ATM to further mitigate adverse air traffic impacts.[256,257]

Looking toward 2040 and 2070, the frontier between aviation and space will become thinner. In the United States, it is the FAA that certifies spacecraft and spaceport operations. There is also a growing interest in higher airspace operations (over

h Achieving ICAO Annex 16, Volume 1 Chapter 4 and U.S. 14 CFR Part 36 Stage 4 standards.

FL500). Operators are deploying suborbital vehicles and high-altitude platform systems (pseudo-satellite aircraft and high-altitude ballons) that will need to cross paths with other airspace users to access these altitudes.[258,259] While xTM should address the need of high-altitude operations, the transit of these vehicles from the ground to higher-altitude airspace shall not create chaos in the already busy portions of airspace which commercial aviation rely on.[260,261]

INTEGRATING NEW ENERGY SOURCES AT AIRPORTS

The main families of aviation fuel are currently the jet fuel (e.g., Jet A) for gas turbines (jet engines and turboprops) and the avgas (e.g., 100LL) for piston-engines. Sustainable aviation fuels (SAF) are aviation fuels produced from sustainable feedstocks such as biomass or waste.[262] They can meet Jet A specifications and be mixed with fuels of fossil origin. While standards require SAF to be mixed with 50% of conventionally produced Jet A, the short-term goal is to certify commercial and business aircraft, including helicopters, to fly with 100% SAF as soon as possible.[263] SAF are drop-in fuels, meaning existing aircraft could fly with 100% SAF without significant modifications.[264] Consequently, SAF can be delivered via existing hydrant systems or trucks. SAF is the main leverage to achieve net-zero aviation by 2050. This will require a massive increase in production and delivery of SAF around the world.[265] Studies have confirmed the technical feasibility of supply chains providing for 100% of the fuel demand at large airports with a carbon-emission reduction of up to 80% across the life cycle.[266,267,268]

Existing airliners could be replaced by clean-sheet, hydrogen-powered commercial aircraft beyond 2040. Airbus and Embraer see this fuel as the key to a low-carbon future without Jet A. Airbus has committed to fly a hydrogen airliner by 2035 (Fig. 20). Through its Energia concept aircraft family, Embraer has called for the development of hybrid-electric and dual-fuel (SAF or hydrogen) gas turbines for introduction beyond 2030.[269] Hydrogen is a potential frontrunner for the long-term horizon through two different pathways. It can power electric aircraft equipped with fuel cells. This

FIGURE 19. RENDERING OF THE NASA/ LOCKHEED MARTIN X-59 QUIET SUPERSONIC TECHNOLOGY ALONG WITH A CONCEPTUAL SUPERSONIC AIRLINER

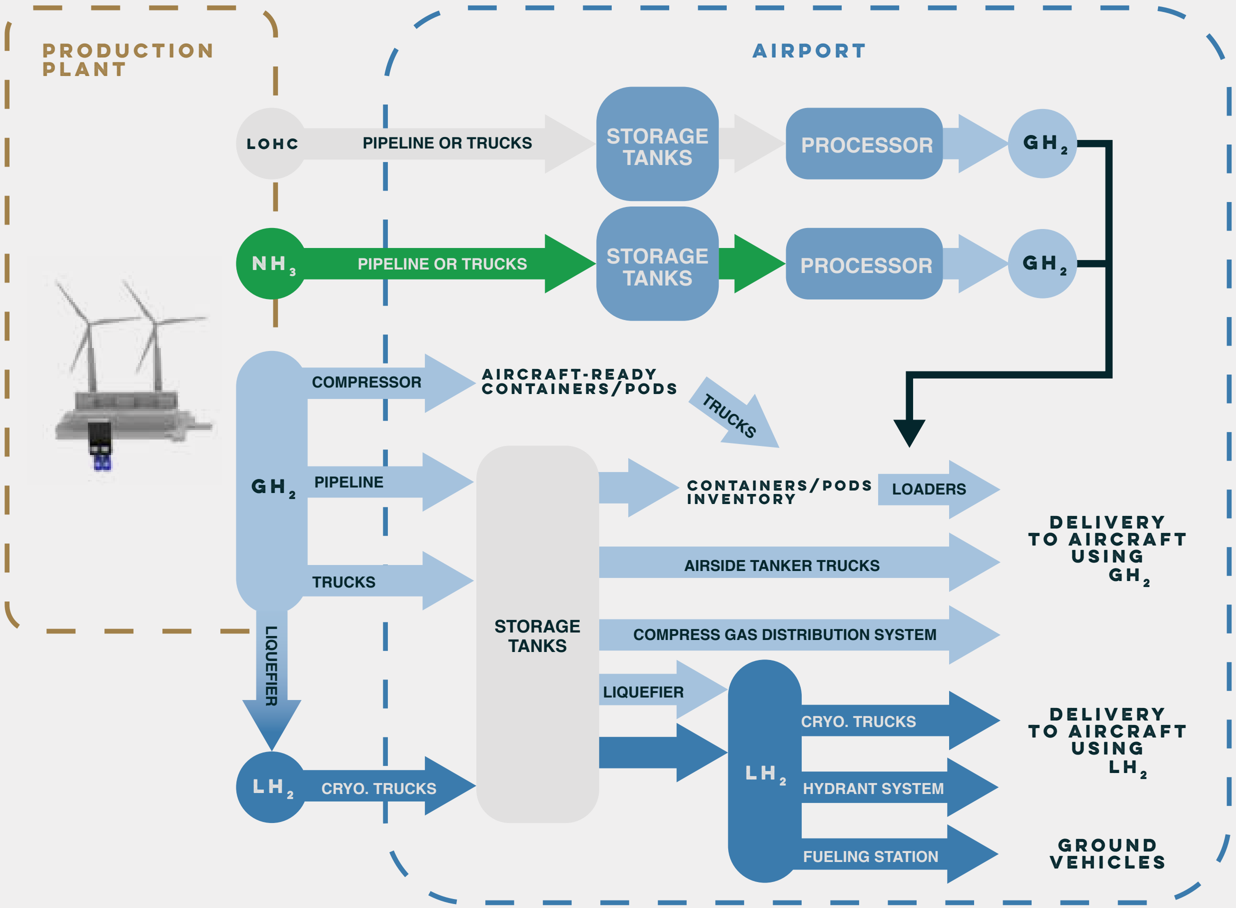
Source: NASA/ Lockheed Martin (2019)

FIGURE 20. RENDERING OF THE LIQUID HYDROGEN REFUELING OF AN AIRBUS ZEROE REGIONAL AIRCRAFT CONCEPT

Source: Airbus (2024)

technology is being considered for regional electric aircraft and VTOLs (e.g., Piasecki PA-380). Hydrogen can also be burned as a fuel in gas turbines. While there is a case for hydrogen-fuel-cell aircraft as part of the emergence of AAM, there is no clear consensus yet over the relevance of hydrogen against hybrid-electric propulsion for larger aircraft using SAF produced via power-to-liquid (PtL). One on hand, hydrogen has the potential to become an ultra-low-carbon-emissions fuel of reference in the context of its broader utilization assuming a green hydrogen infrastructure for supplying it.[270,271] However, the combustion of hydrogen in gas turbines is not entirely greenhouse gas (GHG) free as the process still emits nitrogen oxides.[272] On the other hand, the PtL pathway can theoretically provide a nearly zero-emission fuel without transitioning the aircraft fleet itself to a new fuel. However, PtL is more energy-demanding across the lifecycle and it relies on hydrogen anyway to synthetize hydrocarbons after being processed with carbon dioxide.[273,274] Finally, it ignores direct emissions entirely. Hydrogen has already found its place on markets such as GSE and power generation. Supplying large fleets of aircraft with hydrogen will require new supply chain and a distribution infrastructure which do not exist today (Fig. 21).[275] Also, adequate standards and operational procedures to ensure safe and efficient operations in the airport setting.[276]

Electric and hybrid propulsion systems are a more radical move away from fossil fuels. In addition to reducing emissions, this technology can dramatically reduce noise.[277,278,279] The industry can expect EHPS to provide a durable solution for small general aviation aircraft in lieu of unleaded avgas that is a positive interim fix for existing aircraft to zero lead emissions. But unleaded avgas still emits GHGs, other pollutants, and noise at combustion.



NOTE: **LOHCS (LIQUID ORGANIC HYDROGEN CARRIERS)** ARE ORGANIC COMPOUNDS THAT CAN ABSORB AND RELEASE HYDROGEN THROUGH HYDROGENATION/DEHYDROGENATION REATCIONS. VIABLE CANDIDATES FOR LOHC SYSTEMS INCLUDE CARBON DIOXIDE/METHANOL (CH_4), BENZENE/CYCLOHEXANE, TOLUENE/METHYLCYCLOHEXANE (MHC), NAPHTALENE/DECALIN, N-ETHYLCARBAZOLE (NEC)/PERHYDRO-NEC, DIBENZYTOLUENE (DBT)/PERHYDRO-DBT

FIGURE 21. POTENTIAL HYDROGEN SUPPLY CHAINS FOR AVIATION

Hybrid propulsion systems for transport aircraft should be commercially available by 2035. Transitioning to more electric aircraft will require airports and their stakeholders to invest in charging stations and adapt their power supply.[280] This could enable a push toward local production (e.g., solar farms) and microgrids.[281] To keep e-aircraft competitive for commercial aviation applications, battery charging should not adversely impact the turnaround time. Transitioning to electric aviation will also challenge the business model of the fixed-base operators and aviation fueling service providers.

EMERGING STAKEHOLDERS AND THEIR IMPACT ON COMPATIBILITY

Failure is not an option when it comes to reducing the environmental footprint of aviation and making air travel always more equitable. All the players in the aviation sector are strongly committed to these objectives. The aviation sector has learned to work together to develop a holistic approach of innovation and tackle the various issues that introducing them cause along the value chain i.e., at each stage of the flight and the life of the aircraft. Airports need to prepare for the most likely future scenarios, but also be involved as early as possible in discussions about the adoption of disruptive aviation innovations. In other words, future aircraft technologies shall be not only airport-conscious but airport-friendly.

Awareness about aircraft/airport compatibility is not new. In 1981, Parsons and Wilfert of the McDonnell Douglas Corporation wrote that "on the surface achieving compatibility between airports and aircraft seems a relatively simple task. [...] However, the task becomes increasingly difficult as the details of the design are established."[282] Airport compatibility aspects must be considered early in the aircraft design process. This is especially true when it comes to reinventing aircraft as a whole for the next several decades. More broadly, airport compatibility is concerned with impacts from the landside to the airspace. It is not limited to airfield geometric issues but it should embrace and address airspace operations, airport terminal design, and operations, and noise and emissions aspects as well.

The capacity of an airport to accommodate new types of aircraft in a safe and efficient way lies in the level of cooperation between the stakeholders. While the civil aviation community has reached maturity and accumulated experience in this domain, the emergence of new stakeholders at the visible horizon might require rethinking this order and plan proactively on integrating the new users and service providers within the greater airport family. For instance, AAM has driven the creation of new OEM startups but also new players that are barely emerging (e.g., UAS Service Supplier).

Airport operators themselves evolve and adopt more complex profiles. Public operators, private operators, and more complex models where the airport is publicly owned are all found, but all the terminal facilities are operated by separate private entities competing for airlines.

And what if these airlines splits between flight operators providing aircraft and holding the air operator certificate, and mobility providers developing the commercial offer and selling rides? This expanded wet lease of a new genre could both help to leverage growth in booming regions where flight operators have yet to become safer and reintroduce more diversity on mature markets. These flight operators could actually be the aircraft manufacturer themselves–they already train pilots and lease aircraft. These “compound airlines” could easily be recomposed and adapt to the ever-changing market.

CHAPTER 7

PASSENGER TERMINALS AND CUSTOMER EXPERIENCE

FROM FACILITY PROVIDERS TO MOBILITY AND HOSPITALITY PROVIDERS

Airport operators used to be infrastructure providers, managing aviation facilities as a public service. Because their vision is now more passenger-centric, airport operators consider passengers to be their clients and might sometimes even compete with air carriers on providing customized services to them. The missions of airport operators are evolving as they transition from facility providers to mobility and hospitality providers that compete on the level of service and the experience they offer.

Airport operators are mobility enablers because they are becoming an active part of a broader and seamless door-to-door journey (Fig. 22). Airports are just one piece of this puzzle, but they should work on a better integration and coordination with the nonairport elements, using a holistic customer experience approach. They should control their overall competitiveness and attractiveness in the same way that passengers consider ground accessibility when choosing their airport. [283,284]

Consequently, some airports are developing their own ground transportation offers. Great Western Railway and Heathrow Express Operating Company, a subsidiary of Heathrow Airport Holdings, operate Heathrow Express. Groupe ADP and rail operator Société nationale des chemins de fer français (SNCF) Réseau have created a joint venture to develop CDG Express.[285] Airports are also reorganizing their congested landside for enhancing ground access. For instance, the Landside Access Modernization Program of the Los Angeles International Airport (LAX) is a comprehensive plan to create a remote ground transportation center (GTC) that will be ultimately served by a people mover to ease congestion.[286] It will include a remote curbside for ridesharing.

Airports are also hospitality providers. They provide a simple shelter for passengers waiting for their planes. They are the first impression that visitors get of their destination. They should be a gateway that reflects the region they serve. New York's LaGuardia Airport had been derided for decades for its poor guest experience.[287] Since then, the PANYNJ has signed a PPP for redeveloping and modernizing the whole airport. LaGuardia is experiencing a second life and has become a top-notch facility.[288] Terminal 3 at São Paulo/Guarulhos–Governor André Franco Montoro International Airport significantly improved the customer experience to the best international standards on time for the 2014 FIFA (Fédération Internationale de Football Association) World Cup.[289] Signature atmospheres create a unique experience and often relate to cultural markers of their community. Munich International Airport is well known for its central Plaza featuring pubs and animations. In 2020, Singapore's Changi Airport opened its 135,700-square-meter "Jewel," which features over 300 retail stores and dining facilities across 10 floors, all arranged around a tropical forest with a 40-meter-tall indoor rainfall. Ted Stevens Anchorage International Airport, CDG, and the Beijing Daxing International Airport each feature Alaskan, Parisian, and Chinese cultural elements, respectively, along the passenger journey. Regional airports also seek to provide high-end experiences.

Airports develop services to passengers that may not all generate a net profit alone but have an overall

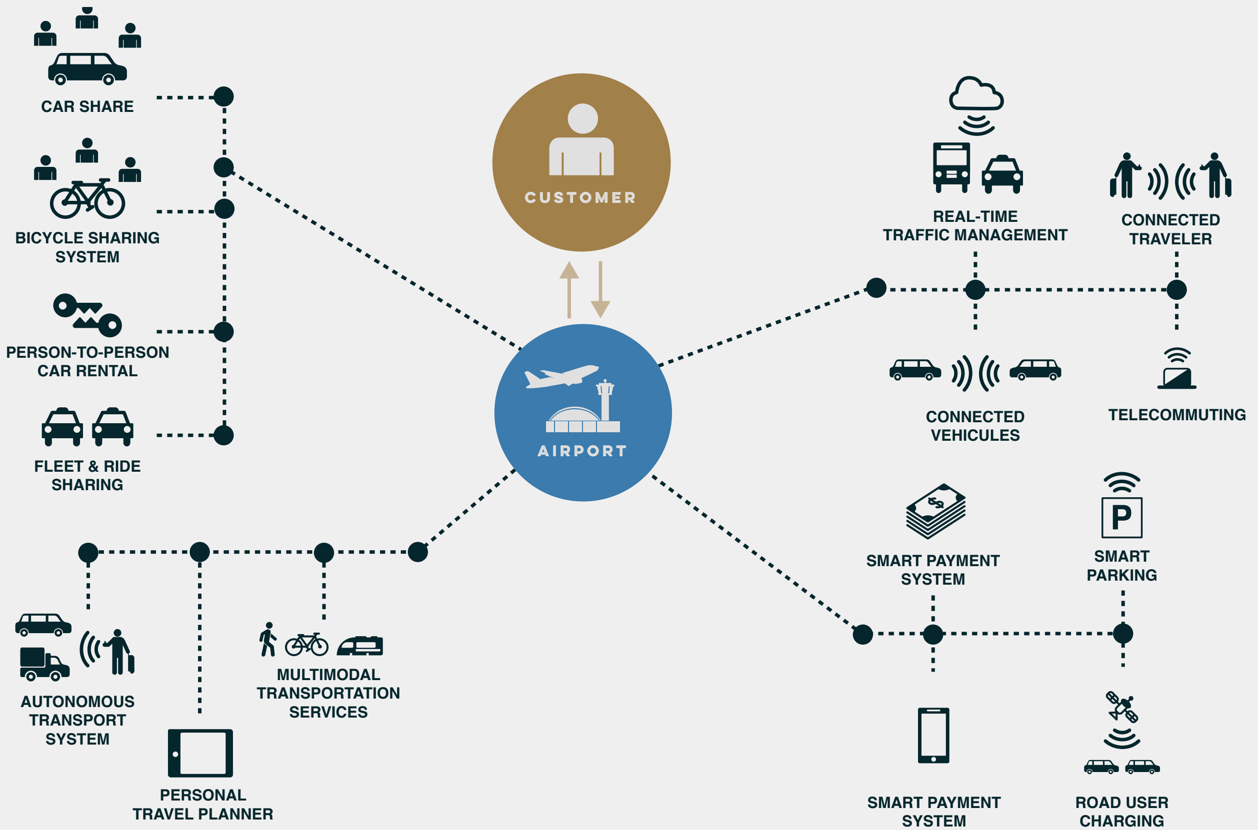


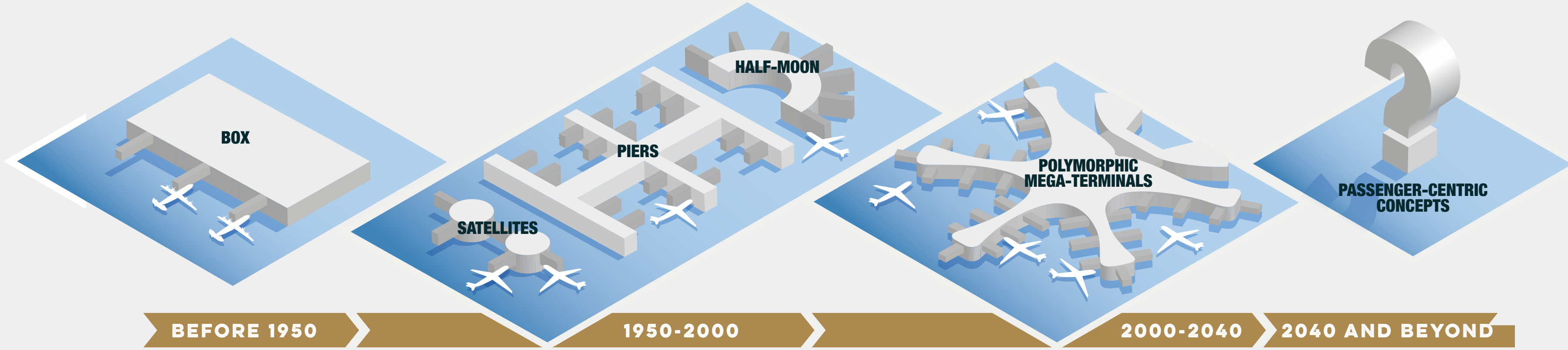
FIGURE 22.

ENABLING DOOR-TO-DOOR MAAS TO THE AIRPORT

positive impact on customer satisfaction. These services include free lounges to connecting travelers, entertainment nearby the hold rooms, concerts and exhibitions, lactation rooms, water stations for replenishing bottles, and even yoga rooms. Some of these innovations, like in-airport hotels, can give airports a competitive edge. The retro TWA Flight Center Hotel is an iconic feature of New York John F. Kennedy International Airport. Airport retails and concessions are another key to generate substantial ancillary revenues. These retail spaces are part of the experience itself (e.g., CDG, LHR, and Dubai International Airport) and can become a differentiator for large hubs. Airports have developed their own loyalty programs with rewards and discounts (e.g., CDG, LHR, and San Antonio International Airport) and customized services such as personal shoppers (e.g., LHR).[290] These services and experiences follow the evolution of the passenger and social expectations. What was once considered as exclusive has become outmoded, as many experiences are now accessible and do not have the same level or glamour as before the era of social- and eco-consciousness.

Supported by intelligent systems that interact with each guest, a passenger-centric experience tailored for each passenger's taste is the way of the future. However, implementing more technology does not mean that airport service employees will go away. On the contrary, airports will need well-trained hospitality professionals. Self-serve amenities are often preferred by most users, but human staffers will be needed to address complex requests, provide a warm and human interface, and ensure resilience if the systems go down.[291,292]

FIGURE 23. CONCEPTUAL EVOLUTION OF PASSENGER TERMINAL FACILITIES



BACK TO THE FUTURE: DESIGNING PASSENGER-CENTRIC TERMINAL FACILITIES

Passenger terminal facilities have changed since the beginning of aviation (Fig. 23). From fairly simple concepts after World War II, they quickly evolved into more complex buildings with the emergence of jet aircraft, the introduction of jetbridges and mobile lounges, and the potential for supersonic commercial flights.[293, 294] The newest, largest facilities have a polyform and centralized layout that can accommodate several million annual passengers under a single roof. However, the size should not hinder the customer experience, operational efficiency, and resilience. Future concepts must achieve simplicity and modularity, which is not a question of building shape or configuration only.

Passenger facilities must go beyond grand architectural designs and get back to the roots of terminal design: providing a straightforward, seamless, and pleasant access to the aircraft from the curbside (Fig. 24). There is a race to the biggest “cathedral-terminal” building between mega-hub airports. But many passengers just want to get from the curb or mass transit station to the gate or from the gate to their connecting flight. Many passengers expect not to have to face a complex itinerary through the airport and spend time changing modes with buses, air trains, and airport people movers (APMs). At the same time, large international hubs compete together, and the entertainment they provide is part of their marketing strategy. Providing a unique experience and promoting retail, food and beverage are conciliable with this prospect.

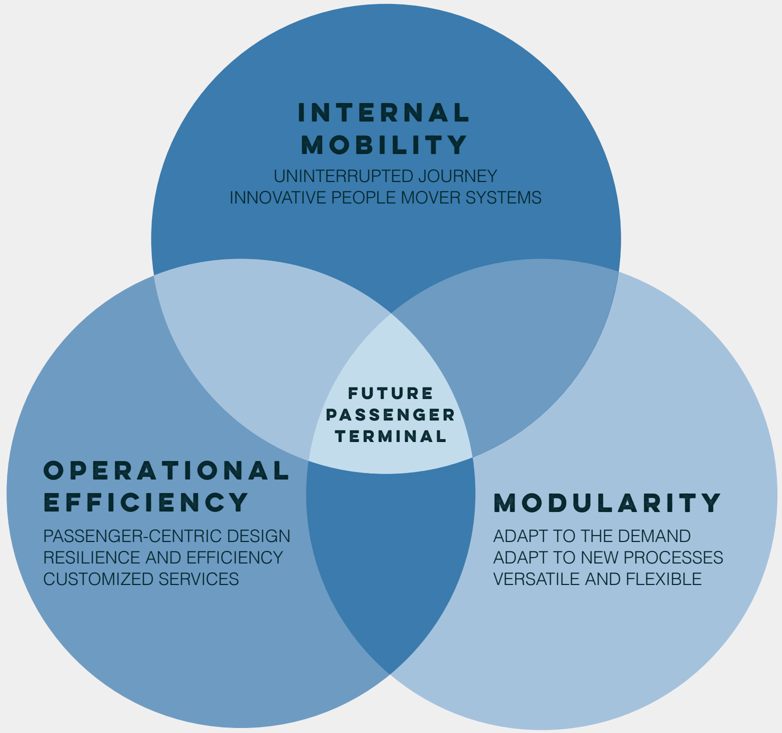
Intra-airport mobility is another issue at many large hub facilities. The passenger journey must transcend terminal concepts, and airports should aim to deliver an uninterrupted journey. Few modes or civil engineering features can achieve this goal. Passenger bridges with mobile walkways over taxilanes (as developed in the Denver, Hong Kong, London Gatwick, and SeaTac Airports) can provide an alternative to APMs. Theoretically, cable cars and personal rapid transit could also provide for a leveled, uninterrupted journey. Mobile lounges are still intensively used at

FIGURE 24. EMERGING ISSUES IN PASSENGER TERMINAL DESIGN

Washington–Dulles International Airport as they allow a flexible use of gates and terminal facilities.[a]

Modularity should be another function achieved by future terminals. While air transportation has experienced sustained, long-term growth, air traffic is also highly sensitive to temporary economic downturns that can lead to market transformations, such as airline consolidations and strategic decisions with impactful decisions for airports, to network restructuring, to more dramatic reductions of the number of airline hubs. The past decade has seen other novelties emerge, such as low-cost, long-range air carriers and narrowbody aircraft being used on long-haul routes that call for more agile passenger facilities that can handle fairly dynamically larger and smaller aircraft, and domestic and international passengers. Geopolitical changes and disruptive events changing standards and practices are other conundrums challenging airports. New technologies might also influence how space and resources are utilized. Self-service bag drops, biometric identity from the check-in to the gate, walk-trough security screening checkpoints, and similar emerging solutions will positively impact passenger flows but also warrant changes in planning and design practices. Modularity and flexibility are keys to long-term success in a changing world that is constantly speeding up.

The concept of wayfinding can be defined as the process of orienting passengers. It is important for airports to address it thoroughly. Effective wayfinding plays a crucial role in helping passengers navigate unfamiliar environments, especially with an increasingly diverse population of travelers. Studies consistently highlight the importance of wayfinding as influential of the overall passenger experience. Although signage alone cannot overcome all physical and geometric complexities, a well-planned wayfinding system significantly enhances passenger flows and one's individual experience throughout the facility. Challenges arise from varying standards and practices among operators and even stakeholders at the same airport, with the signage being governed by different priorities and standards while lacking comprehensive industry codification.



Digital technologies can help enhance wayfinding. Applications for smartphones and other mobile devices can serve as robust alternatives for wayfinding, offering georeferenced information customizable to the needs of specific user groups, accommodating multiple languages with minimal impact, and providing tailored strategies (e.g., suggesting less crowded pathways for individuals with hidden disabilities). Applications also provide

a The use of these vehicles was discontinued at other airports mainly because of their operating costs. However, large hub Some aairport (viation facilitiesmost of them in North America) (ATL, YUL) hasve kept a few mobile loungesof them as a contingency plan for supporting remote operations.

information on the airport access options available, such as location at the airport, pricing, availability, congestion level, and disruptions. Furthermore, airport applications can either redirect to mobility providers or integrate these offers with a MaaS approach to enable trip planning and booking.

In the end, getting the basics right is as important as creating a "wow" effect. The top priority of most passengers is either locating the departure gate or recovering their bags and securing a ride to arrive on time to the final destination.[295] Applications and services may alleviate this mental load, improve the experience, and perhaps increase ancillary revenues. But basic does not mean inexpensive. No-frill terminals show their limits because they do not meet the passenger expectations. The gap between passenger expectations and terminal bottom lines is a difficult paradigm to address for airport operators that need funds to maintain or upgrade their facilities while facing a strong opposition of air carriers to collect adequate user fees to do so.[296,297,298]

THE UPCOMING BATTLE FOR DOOR-TO-DOOR SERVICES

The lack of regional integration and custom unions are an increasing concern for arriving passengers in some parts of the world. Travelers enjoy free movements without border control within the European Schengen Area. Citizens of the Southern Common Market (MERCOSUR) can travel within the block with their national identification cards only.[299] Visa exemptions (e.g., CARIPASS, ESTA, ETA, ETIAS) and simplified electronic border controls (e.g., eGate, Global Entry, NEXUS, SENTRI, SmartGate, PARAFE) expedite border controls. Most ASEAN nations have mutual visa-free policies toward visiting citizens of other member states but rules vary among countries. The implementation of a visa-free area within the African Union is still a work in progress.[b] Passport controls have been mentioned as one of the first negative points of the journey by passengers within these regions.[300,301]

Efficient and passenger-friendly terminals are a key competitive advantage for air carriers. Individual carriers and wider alliances are spending a large amount of money to modernize terminal facilities and customiz them to offer a consistent high-end experience from airport to airport. For instance, Delta Air Lines is investing $12 billion over a five-year period in airport infrastructure with flagship projects around the United States, and took ownership in 2016 of 5% of CLEAR—a private biometric screening process.[302] Outside of the United States, airlines frequently do not own their passenger terminal facilities. Their brand is typically less visible, and they might share airport-owned infrastructure and equipment with other air carriers. In return, airports are competing to attract and retain these air carriers. This competitive edge of airlines at airports cannot be achieved without a close cooperation between airport or terminal operators and innovative partnerships with service providers.

In terms of competition, the next frontier could be on the first and last miles–from the door to the curbside. Airlines and airports might team or at least better coordinate with transportation network companies to simplify

b The Free Movement of People and the creation of an African Passport are two initiatives of the African Union's Agenda 2063.

this part of the trip. It is already possible in some cities to check-in bags at hotels or the train station to the airport. Additional services will be proposed, such as the baggage pickup and delivery at home or the workplace. This is one of the multiple innovations that could help passengers extract value out of their entire trip door-to-door. A seamless journey should allow clients to work, join a meeting, or be entertained during their trip including in the transit to the airport or final destination. Watching a movie on a smartphone with a bad connection or using a computer in precarious conditions is not what 21st century citizens deserve. As we now spend a significant part of our life in transportation, we need to unlock this lost time to make it available and effective. New technologies and behaviors might facilitate this move. Carry-on bags become lighter under the pressure of higher air carrier fees. Computers might become more portable with applications and files available everywhere through cloud-based solutions.

CHAPTER 8

OPERATIONAL PERFORMANCE AND RESILIENCE

AIRPORTS AND AVIATION SYSTEMS ARE INCREASINGLY SENSITIVE TO DISRUPTIONS

Airports and aviation systems are complex ecosystems that support a global economy and provide for the safe and efficient movement of passengers and cargo. According to the Air Transport Action Group, aviation supports 65.5 million jobs worldwide and enables $2.7 trillion[a] in global gross domestic product (GDP).[303] In average, over 45,000 flights are controlled daily in the United States[304] and over 30,000 in Europe.[b,305] A significant disruption in the skies or at a single commercial service airport can rapidly cost millions USD to the society. A power outage at Hartsfield-Jackson Atlanta International Airport in December 2018 led to the cancellation of 1,400 flights and cost between $25 and $50 million to Delta Air Lines alone. Eurocontrol considers that the cost a flight cancellation ranges from $7,000 to $125,000, including the passenger opportunity cost. The tactical (last-minute) delay to airlines can range from $40 to $200 per minute.[c,306]

While crises such as the Great Recession and the COVID-19 pandemic have short-term adverse effects, air traffic has a proven long-term resilience that leads forecasters to predict a world annual growth rate of at least 3.5% to the 2040 horizon.[d,307] Beyond 2040, the rise of Africa will continue to support this growth worldwide for several decades. Innovative air mobility will create a new demand as well. Enhancing the accommodation of this growing throughput with improving punctuality and resilience has been one of the main concerns of the air traffic management modernization effort that the world has undertaken under the umbrella of the ICAO's GANP. Leading local programs include NextGen in the United States and the Single European Sky (SES) in Europe. Other programs include Sirius in Brazil and CAAMS in China,[308] and other countries are modernizing their ATM as well without a centralized management and branding.

Within an interconnected air traffic management process such as the U.S. National Airspace System or the SES, issues faced by a single commercial airport and their impacts on the overall performance of the network have been highlighted. For instance, Welman et al. estimated in 2008 that 1 minute of original delay at a U.S. hub airport resulted in 1.44 to 2.16 minutes of total delays considering the propagated arrival delay distributed across arrivals at one or more airports.[309] Airports are more interdependent and there is a need for an emerging concept of accountability for the delay one creates on the overall airport ecosystem. The SES approach includes a performance and charging scheme on air navigation services with an airport component.[310]

---

a 2005 USD. 1 trillion = 1,000,000,000,000.

b Flights controlled by European Civil Aviation Conference (ECAC) members.

c Rough orders of magnitude in EUR_{2020}. Original figures in EUR_{2018} adjusted to inflation. 1 $EUR_{2018} \approx 1.02$ EUR_{2020}. 1 $EUR_{2020} \approx 1.1$ USD_{2020}.

d Compound Annual Growth Rate (CAGR) of the Revenue Passenger Kilometers (RPK) over the 2012-2042 ($ICAO_{2016}$).

COLLABORATION HAS BEEN A GAME CHANGER

Collaboration between the stakeholders of real-time operations has been a game changer everywhere it has been implemented. The different organizations representing all the stakeholders of airport operations have called for the end of the "silo effect" [311] and have supported CDM.[312,313] Airport CDM is now an international standard[314] and an objective of ICAO for advancing air navigation as part of the GANP.[315] The Airport CDM concept that emerged in 1990 is about establishing a closer relationship among the players of real-time airside operations and sharing information for the purpose of enhancing efficiency, reducing delays, and improving resilience. The Airport CDM culture is based on trust and transparency to serve the common operational interest. One of the focuses is to create a framework for the stakeholders to share operational data, have the same level of information, and decide collaboratively–not side-by-side only anymore–on how to address operational issues in a timely manner. The extension of this approach to the rest of the airport, from the access road to the airfield, is called TAM. A practical application of TAM is the APOC, which integrates the different functions of real-time airport operations into a single physical or virtual facility with, as far as possible, the participation of all the internal stakeholders of the airport authority and the external stakeholders as well.

To successfully collaborate, everyone needs to speak the same language and agree on set objectives and consensual remedies to adverse conditions. Stakeholders at pre-Airport-CDM airports have notoriously different definitions for the same milestones of the flight turnaround process. Airport CDM brings a common framework with joint key performance indicators and definitions on airport performance and capacity.[316,317] Freed from their cultural differences, the airport operations community can focus on monitoring these key performance indicators, detecting coming adverse conditions when possible, and proactively managing them together.

After establishing a list of flights and their reference times (milestones) updated by each stakeholder for real-time operations and short-term planning purpose, expanding this vision months before for long-term operations planning is possible, considering the evolution of the demand and any foreseen change in capacity (e.g., due to construction projects). Most of the commercial service airports already have an operations planning process. But an Airport-CDM vision of operations planning as promoted by ICAO in the GANP under the name of Airport Operations Plan (AOP) is the ultimate step of implementation for integrated planning and management of operations. In Europe, the AOP concept of EUROCONTROL looks 180 days ahead and informs a network-wide operations plan.[318]

The benefits of collaboration are tremendous. A 2016 assessment by EUROCONTROL shows that across 17 CDM airports in Europe, Air Traffic Flow Management delay has been reduced by 10.3%, the average taxi-time by 7%, and the fuel consumption, carbon dioxide and sulfur dioxide emissions by 7.7%.[319] Europe and the United States have pioneered CDM. In Europe, CDM started from airports, and this recipe has been applied all around the world. These local Airport-CDMs feed a network-wide CDM model. In the United States,

FIGURE 25.
EVOLUTION OF INFORMATION SYSTEMS FOR AIRPORT OPERATIONS

CDM started from the FAA Air Traffic Control System Command Center and the air carriers under the FAA/Industry CDM Stakeholders Group. There is a network CDM, but not yet local airport focused CDM as it can be experienced elsewhere. In the future, airports must be included as well, and several initiatives aim at giving a push to this movement, especially on the collaborative management of adverse conditions.[320]

FROM REACTIVE TO PREDICTIVE MANAGEMENT

The step forward will be predictive management (Fig. 25). Advanced collaboration has made available a large quantity of flight operations data collected into Airport Operations Databases and other repositories. Processing these data through intelligent systems to predict potential disruptions, trigger preventive actions before disruptions happen, and mitigate a disruption's effects is now possible. Moreover, this predictive management approach might be the next step in the advancement of airport and air navigation management while major modernization programs such as SESAR and NextGen are ending, and the ICAO GANP itself does not provide a framework for the period beyond 2030 yet.

Information systems are enabling the current modernization effort in the airport and air traffic management. Intelligent systems will power the continuation of this effort toward a more capacitive, integrated and resilient aviation system, from the landside to the airspace. In the air, air traffic control is at the threshold of more automation. Most of the optimizations that are achievable under current concepts of operations have been implemented. For instance, the Wake Turbulence Recategorization has introduced new categories of aircraft for safely decreasing wake turbulence separations between some pairs of aircraft categories. The next step could be to characterize additional aircraft pairs, with more categories or even by aircraft types. Ultimately, these separation minima could take into consideration local parameters, such as wind, and flight information, such as the weight of the aircraft. Such progress could increase capacity but is not achievable without a higher degree of automation in air traffic control, providing the controller with a visual aid on the minimum separation between a given pair of aircraft or the automation of this instruction. Similarly, building on the experience of the pre-departure sequencers of the Airport-CDM solutions, based on up-to-date flight key schedules and infrastructure capacities, air traffic controllers managing ground movements at large airports could be supported by ML from the local specificities, including the choices made by the controllers and AI to optimize dynamically taxiing. Georeferenced mapping information for enhancing navigation on the ground could be transmitted by datalink to the cockpit as well. This information could consider all active ground movement restrictions (e.g., aircraft type limitations, and work in progress) for improving safety, mitigating incidents, and taxi efficiency.

On the landside and in the terminals, intelligent systems can assist the operations community in optimizing resources and proactively identifying coming demand-capacity issues. Many airports are already equipped with sensors or systems for measuring passenger flows and queues. Simple algorithms can be used to deduct the resource needed to process this throughput. ML could recognize patterns in these flows, understand how the resource dynamically responds, and provide advice and scenarios to operations manager on the best way to proceed. Augmented reality and other advanced interfaces can enhance the visualization of these scenarios and data to facilitate their understanding and use. With the implementation of self-service devices and automated control systems, part of this decision-making process on resource management might start being automated or semi-automated by 2040. Significant progress can be made outside of the terminal building as well. Ground resources are often congested or used in a suboptimal way. A CDM-like coordination between airport operators, ground mobility providers, and transit agencies is emerging and will bring tremendous improvement. Adding potential transfers or rebooking between the air and rail modes would be an innovation and was explored as part of the EU-funded research project META-CDM.[321] The introduction of connected and automated vehicles (CAVs), as well as UAM could open new horizons on the coordination of the ground transportation offer to fit the demand, increase predictability and reliability, and reduce congestion and waiting times.

Such systems will need adequate infrastructure to exchange data. The System Wide Information Management (SWIM) is a global air traffic management initiative that offers a data-centric framework for sharing these data. SWIM is one of the ICAO GANP items to achieve the global interoperability of systems and data. Although SWIM has been designed for minimizing the interfaces and standardizing data sharing between the stakeholders of air navigation and flight operations management, it is a powerful system. It has the potential to bring together more aviation stakeholders (or at least inspire a broader pan-aviation framework) that could exchange information with non-airside parties, interconnect with non- Air Traffic Flow Management systems (e.g., future digital infrastructure for collaborative ground traffic management), and even enable data exchange with passengers.

Digital twins is another airport application of big data and intelligent systems to foster efficiency and resilience. A digital twin of a system is a digital replica and a detailed model of physical assets and processes that can be used for predicting and anticipating future issues or simulate scenarios. Airport digital twins can help with planning maintenance actions for asset management and financial planning purposes. They can also be used for running detailed and realistic "what-if" scenarios of future operations and provide extensive help to stakeholders to plan for future activity, optimize resources, increase revenues from retail, or facilitate the commissioning of new facilities.

PERFORMANCE AND RESILIENCE THROUGH HUMAN-AI COLLABORATION

Resilience starts on the first day of operations of a new facility with the Operational Readiness and Airport Transfer process. The commissioning of a new facility can be challenging, especially when a massive capacity is being delivered at the same time such as the new Beijing Daxing International Airport and Istanbul Airport. Architects, designers, and engineers must keep in mind that innovation should ultimately serve the operations. The first intelligent systems in aviation are the aviation professionals. Airports must be easy to maintain and operate. Changing a light fixture should never require custom-made equipment. Mechanical, electrical, and plumbing systems must be accessible to maintenance teams. An airport is a design masterpiece only if it looks beautiful *and* operates efficiently at the same time. Decision-makers should maintain awareness that if cost-saving policies and operational requirements are not balanced, efficiency and resilience will be at risk. A well-planned preventive maintenance program saves money and redundancies are never regretted the day they prevent an airport from shutting down.

While information and intelligent systems can enable more performance, efficiency, and resilience, systems expected to make us more resilient must not actually make airports weaker. Indeed, these systems themselves can fail. Beyond redundancies and failsafe designs, simple contingency plans can be prepared to maintain the activity based on less "techy" processes even if it means to operate in degraded mode. For instance, Geneva Airport operators train agents to process passenger boarding with paper documents to continue operating in case the gate's computers or readers are out of order. These "what-if" based training strategies can save the day as airports become increasingly dependent on technologies and systems.

Enhancing the long-term resilience to sudden shocks of demand, such as the COVID-19 crisis, is possible. Such a strategy requires an interdisciplinary approach that goes beyond the means and powers of the aviation industry and should be led or coordinated by governments and international organizations. Although COVID-19 itself could not have been foreseen necessarily, the emergence of a new pandemic of respiratory disease after severe acute respiratory syndrome (SARS) and Middle East respiratory syndrome and their effects on society and the economy was predicted. Unfortunately, despite these warnings, our nations were poorly prepared when the SARS-nCOV-2 virus spread around the world at the beginning of 2020. What will be the next pandemic? A new influenza or coronavirus pandemic will happen someday, and the lessons learned from the COVID-19 pandemic should be used to making society more resilient overall. In addition to viruses, new forms of terrorism, the collapse of IT infrastructure, collateral casualties of conventional wars, and the impact of extreme weather due to human-induced climate change are other threats to aviation. Transparency, collaboration, and planning are keys to prevent adverse events and provide an adequate and timely response when required.

CLIMATE CHANGE WILL CHALLENGE AVIATION SYSTEM RESILIENCE

Climate change raises specific threats to resilience. Its effects on our infrastructure systems were already visible in 2024. Significant climate anomalies with a direct impact on our lives have now been recorded for over two decades (Fig. 26-27).[322,323] They range from frequent record high temperatures to violent winter storms, and they have direct consequences on the health and availability of airport assets and both the operating and capital expenditures. Some of these events have created new paradigms regionally. The winter season 2010–2011 in Europe led to significant investments in winter equipment and support facilities, an effort to make operations more resilient. Similarly, Kansai International Airport decided to heighten seawalls and its runway by 1 meter following the damages from typhoon Jebi in 2018.

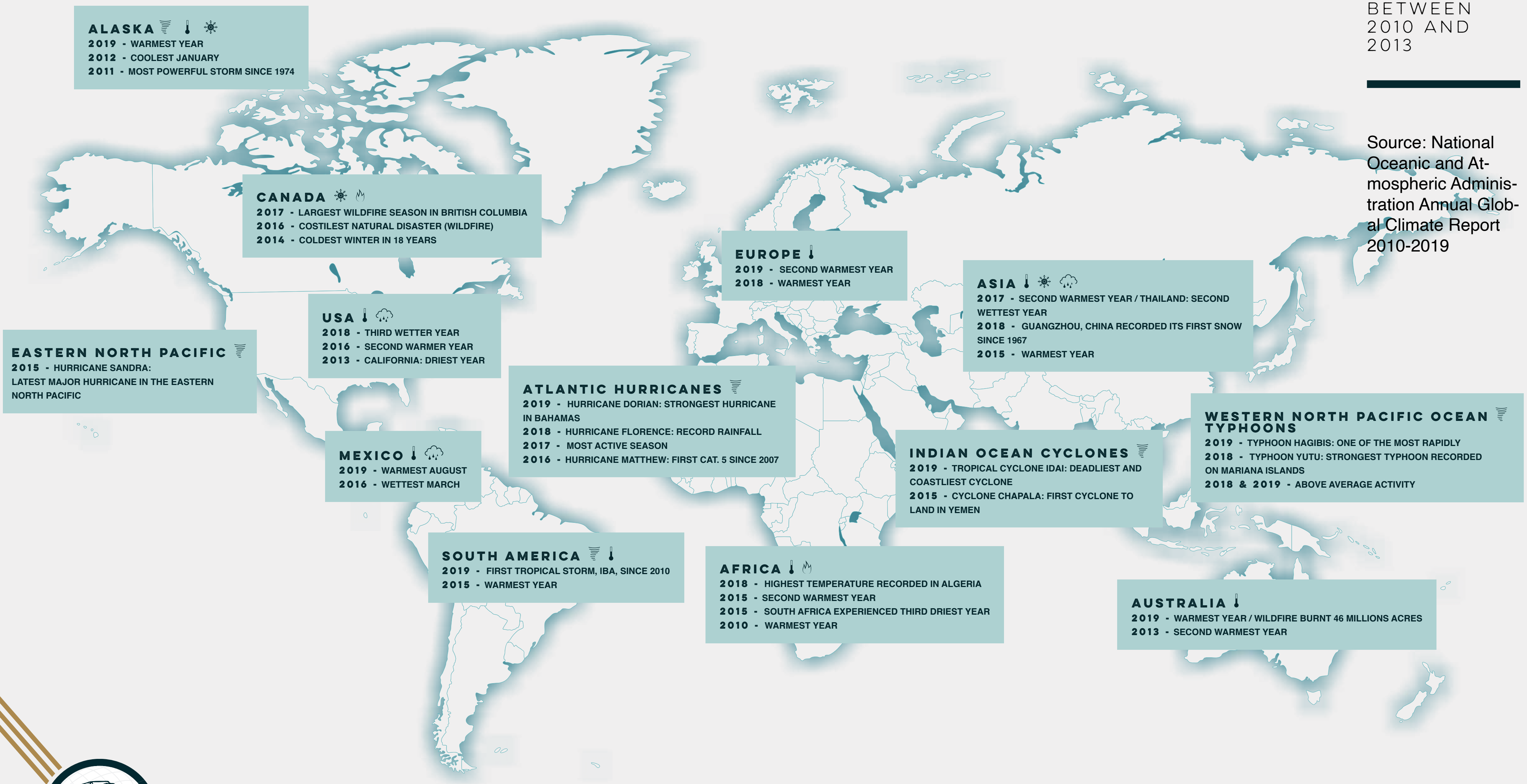
Beyond the extreme weather conditions, the overall climate is evolving. According to a study by ETH Zürich researchers, the 2050 climate in London will be more similar to the current one in Barcelona. Seattle might experience conditions closer to today's San Francisco. Nairobi might feel like Maputo, and Tokyo like Changsha (Fig. 22).[324] Such changes will redefine critical criteria for airport design and operations such as the 100-year floodplain, the average temperature, and even the windrose.[325] A significant change in climate might also have an impact on soils. Airports most exposed to geotechnical changes are the facilities in the polar regions that are built on permafrost, which is changing under the warming of the climate.[326]

The climate is warming globally on average, but it is also becoming more unstable, creating more anomalies that affect air traffic and damage infrastructure. For instance, NASA predicts an average of two to three days of additional days of thunderstorm conditions annually beyond the 2070 horizon compared to the second half of the 20th century.[327] Research works suggest that extreme El Niño–Southern Oscillation events could be more frequent.[328] These events could include wildfires in Australia and Southeast Asia (haze and low visibility) and heavy rains in Peru and Ecuador (flooding and erosion). In 2004, the southern states of Brazil experienced the landfall of Hurricane Catarina–a first by the weather records available.[329]

Global warming will have impacts on airport operations. Because of climate change, extreme cold weather may

FIGURE 26. SELECTED CLIMATE ANOMALIES BETWEEN 2010 AND 2013

Source: National Oceanic and Atmospheric Administration Annual Global Climate Report 2010-2019



- IN EUROPE, CITIES WILL BE WARMER BY **3.5°C** IN SUMMER AND BY **4.7°C** IN WINTER IN AVERAGE
- **77%** OF CITIES WILL EXPERIENCE STRIKING CHANGES IN CLIMAT CONDITIONS BETWEEN NOW AND 2050

FIGURE 27.

COMPARISON BETWEEN CITY ANALOGUES FROM A CLIMATE PERSPECTIVE

Source: Understanding climate change from a global analysis of city analogues, ETH Zurich, PLOS ONE, 2019

occur even at locations that are usually spared by frost, which could mean increased deicing activities. While the frost-free season will be longer at several airports of the temperate zone,[330] winter storms could become more frequent. To cover the same level of risk on operations as of today, airports and their stakeholders may have to conduct investments with lower benefit-cost ratios. Climate change will have a broader impact on operating costs. An increase in hot days will trigger a higher utilization of air conditioning in the passenger terminal buildings and can impact the commercial payload of some flights.[e] They will require construction projects to consider higher contingencies for covering interruptions and delays due to adverse weather conditions, including heavy rain and heat waves.

One of the most impactful and dramatic effects of climate change is the rise in the average sea level. Coastal airports and metropolitan areas are

e This statement applies to existing aircraft types only as new aircraft types have better takeoff performances.

directly threatened by the rise in the sea level. Models show that some metropolitan areas might be permanently underwater.[331,332] Most of the Asian delta areas are terribly exposed. By 2070, most of Bangkok, Ho Chi Minh City, Shanghai, and Tianjin could be permanently flooded if massive adaptation plans are not undertaken. Annual and decennial flooding events would flood commercial airports such as RIOgaleão–Tom Jobim International Airport, , John F. Kennedy Airport, LaGuardia Airport, Philadelphia International Airport, Santos Dumont Airport, San Francisco International Airport, Venice Marco Polo Airport, Amsterdam Airport Schiphol, and London City Airport under the same assumption. Some inland facilities are not necessarily spared by the redefinition of extreme flooding scenarios due to more violent rainfall events.

TRB identifies five key issues regarding climate change resilience for transportation infrastructure: Using climate information to improve risk-based decision-making.

1. Communicating adaptation successes to individual local governments.

2. Building flexibility and adaptability into policies, designs, and standards.

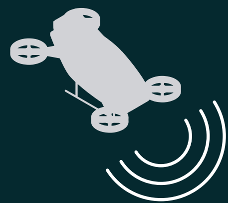
3. Making a business case for adaptation.

4. Facilitating managed retreat and discourage risky investments.[333]

Major civil engineering work may to be conducted to increase the climate resilience of several airports. Kansai International Airport is the perfect example of the symptoms and remedies that other airports may face. After the damage caused by typhoon Jebi in 2018, the airport dramatically expanded its flood protection measures to address sea level rise and more frequent and intense extreme weather events.[334] New facilities will have to be designed to sustain the conditions of the long-term future. Ultimately, retreating will be the most adequate scenario for some facilities that are excessively exposed to extreme weather events (e.g., aerodromes subject to permanent flooding unless costly actions are not undertaken and located in communities declining due to the rise of the sea level).

CHAPTER 9

MOBILITY AND COMMUNITIES



AIRPORTS ARE PART OF THE COMMUNITY

Airports do not have "surrounding" or "neighboring" communities. They are members of these communities. Depending on the matter, airport communities can take different forms and meanings. For the purpose of this paper, the concepts of inner and outer communities are defined. Their exact extend and composition might vary from an airport to another.

The inner community, which is in the direct vicinity of the airport, is exposed to specific, direct economic benefits but also negative externalities (higher noise exposure). The inner community includes cities where the airport is and adjacent communities that depend on the airport economically or are directly exposed to its externalities (Fig. 28).

The outer community is served by the airport and may include the macro-region. The outer community encompasses a large diversity of parties that benefit from or are concerned by the airport. This includes local passengers flying their community airport, business and economic development community looking for a dynamic airport supporting them with more direct flights, local governments, and various agencies involved with the wide range of airport-related challenges and opportunities, etc. Its footprint could include the metropolitan area and a broader region, depending on the aspects considered. Large hub airports are gateways for entire regions and countries, while airports in remote and scarcely populated areas enable opportunities for vast territories.

FIGURE 28. INNER AND OUTER AIRPORT COMMUNITIES

Source: Understanding climate change from a global analysis of city analogues, ETH Zurich, PLOS ONE (2019)

INNER COMMUNITY: MITIGATING ADVERSE IMPACTS AND MAKING THE AIRPORT A CENTER FOR OPPORTUNITIES

The inner community of the future should be connected to and supported by its airport. Adverse impacts (in particular, noise) must be better taken into considerations in countries where land use policies and insulation programs are not yet in place or enforced. But community issues go beyond the noise and pollution aspects.[a] Accessibility around an airport can be paradoxically an issue when all ground transportation is directed toward the airport and designed to move passengers to other centers of residence, consumption, and decision. Airports should be an opportunity to better connect territories and communities—not to divide or isolate them further. Mobility on and around airports should be improved, and it can be a testbed for sustainable solutions to prevent negative impacts on local air quality. Airports like Amsterdam Airport Schiphol or Zürich International Airport are exemplary regarding local mobility with multiple modes serving the airports and extending to communities around–especially bike lanes and bus services. At the airport itself, multimodal hubs and other GTCs facilitate the connection between the airport and the local public transportation.

Airports increasingly promote recruitment in their inner communities to foster the integration of their population, reduce unemployment, provide opportunities for social mobility, and grow an airport-centric community. In return, a dynamic inner community can develop a whole ecosystem of small businesses that can ultimately connect to airport-based activities and an airport trade center. This is a positive dynamic that can be promoted by an adequate holistic vision of airport strategic planning. Airports and local governments should work closely to coordinate plans to achieve these objectives. Similarly, the airport and local long-term visions and plans should align—or at least be consistent. This requires a continued partnership for success between governments and their respective planning initiatives. Ideally, the nearest and most exposed land around the airport should be prioritized for industrial, commercial, and greenspace purposes. In light of the COVID-19 pandemic, recruitment strategies may necessitate adjustments in response to notable changes in air travel patterns, altered passenger behaviors, and the economic challenges posed by the pandemic. The increased prevalence of remote work and the growing significance of virtual communication have introduced new dimensions to the dynamics of inner airport communities and their connectivity to surrounding areas. As more individuals engage in remote work, the traditional commuting patterns and daily interactions within airport communities might evolve.

While the ideal exposed land around airports should be industrial, commercial, and greenspace, several airports around the world have residential areas in their immediate vicinity. These areas are often inhabited by lower-income households and voiceless communities. Sometimes, these communities relocate around airports after being pushed out of their original settlements because of uncontrolled gentrification without social justice. Climate gentrification might make this phenomenon more severe. At the same time, the same lands around airports could become targets for industrial or business real-estate developers. This potential development calls for a special attention to social justice in planning. Comprehensive and inclusive public involvement and community

a See Chapter 10: Sustainable and Net-Zero Airports.

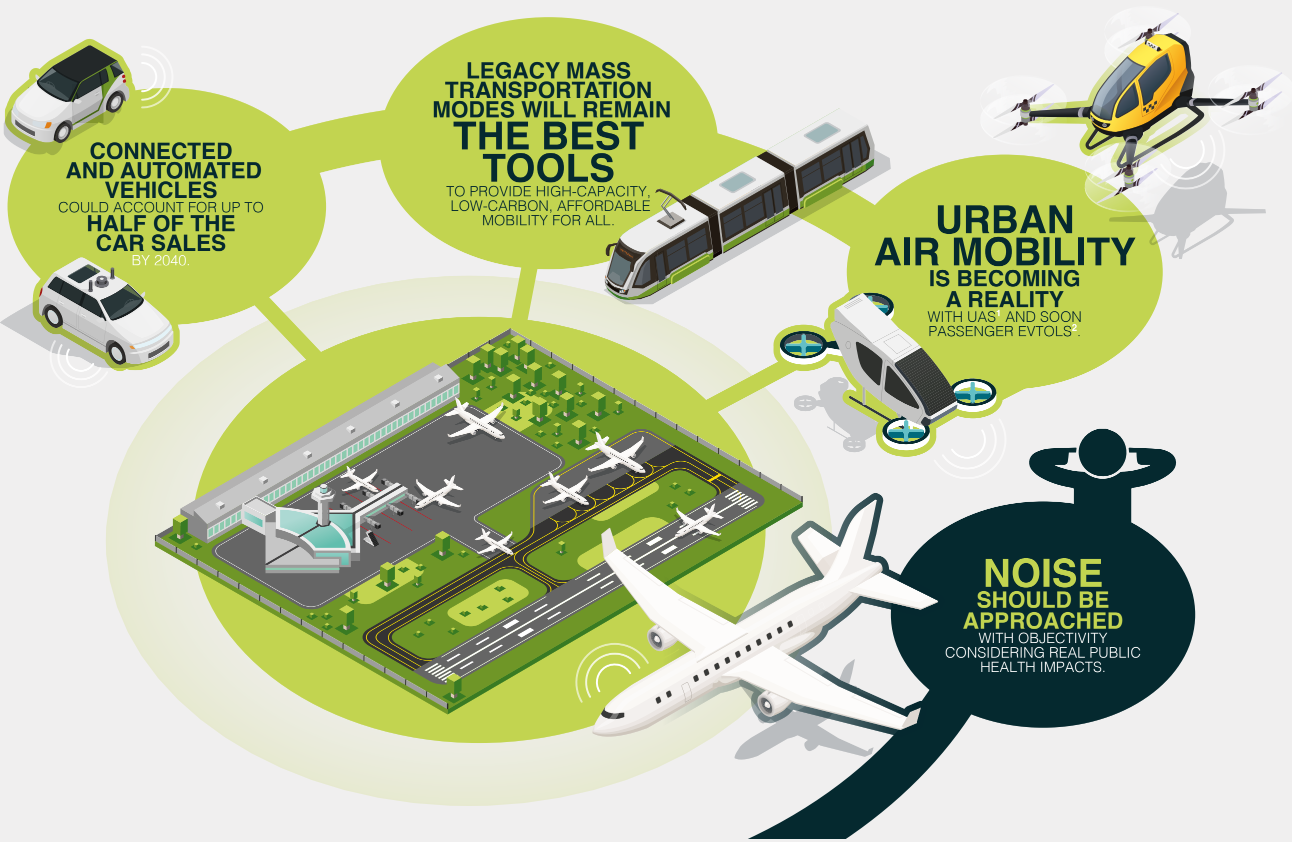


FIGURE 29. AIRPORTS AND THEIR COMMUNITIES: ADDRESSING MOBILITY AND NEGATIVE EXTERNALITIES

[1] UNCREWED AERIAL SYSTEM [2] VERTICAL TAKEOFF AND LANDING AIRCRAFT

outreach are vital for ensuring a fair and just representation of the local population and compensation when insulation or relocation are warranted. Local governments and airports can also be innovative. For instance, participatory democracy has shown great achievements in directing funding toward projects improving quality of life, beautifying neighborhoods, and enhancing the engagement of local residents.[335]

OUTER COMMUNITY: ENHANCING MOBILITY ON THE GROUND AND IN THE AIR

One of the main challenges of the 2040 and 2070 horizons for airports serving large outer communities will be mobility. Virtually all major metropolitan areas are facing some kind of acute congestion symptoms. Bogota, Boston, Istanbul, London, Los Angeles, Mexico City, Moscow, Rio de Janeiro, Roma, and São Paulo are among the worst cities in the world for the average accrued number of hours spent sitting in traffic annually. Accessibility has a direct impact on the attractiveness of airports as both transportation mode and workplace. Roadway congestion in large metropolitan areas has been identified as a potential hinderance to future airport growth since the early 1970s. In many cases, the development of highway systems improved travel times and provided temporary congestion relief. However, the sustained growth of many large metropolitan areas developed around car-centric patterns have created bottlenecks that can seriously impact airport attractivity.

We are at the edge of a revolution

in urban mobility, and airports shall embrace it in order to increase their attractiveness and their connectivity to their communities. Mass transit is being implemented in new cities, including countries that have been historically reluctant to fund public transportation systems. Bus Rapid Transit (BRT),[336] which emerged in the 1970s in Brazil and Canada, is sometimes seen as a less expensive and more flexible alternative to light rail as it can leave the dedicated BRT lanes to extend services on shared roads.[337] Intercity and high-speed rail corridors are conquering new territories–such as Central Florida, Texas and the West Coast of the United States.[b] More direct trains are being built to connect airports to downtowns (e.g., Paris, São Paulo).

The recent years have seen the emergence of various transportation innovations that could enhance airport access.[c] For instance, CAV technologies may alleviate curbside congestion at airports. They could also be used for creating new on-demand service in underserved areas. Once these technologies are mature, they might also enhance roadway safety. However, as CAVs could optimize the utilization of roads through network coordination using AI, they will not provide a relief to existing congestion as they share the scarce ground-level resource available with existing modes and vehicles. CAVs will actually replace or add vehicles to the existing traffic. If they are highly affordable, the CAV-based mobility offer might even seduce current public transit users, taking resource away from it and worsening congestion.

Innovations intending to solve the urban congestion equation are bypassing roadways and going underground, in the air, or on water (Fig. 30). Some of them, such as urban air mobility (UAM) and advanced water taxis, rely on small vehicles carrying two to six passengers to provide on-demand mobility. However, the typical passenger throughput of the largest hub airports is over 50,000 daily passengers. This is comparable to the entire population of a small

FIGURE 30. INNOVATIVE MODES OF TRANSPORTATION CAN HELP RELIEVING ACUTE URBAN CONGESTION

b Brightline started express services to Orlando International Airport from South Florida in September 2023.

c See Appendix P: Existing and Emerging Modes of Transportation to Airports.

urban area, per the Organization for Economic Cooperation and Development definition. In 2019, the world's busiest airport, Hartsfield-Jackson Atlanta International Airport, accommodated nearly 300,000 passengers daily—approximately the number of inhabitants of Pittsburgh, Pennsylvania.

While it might prove relevant to transport some passengers and create new services, innovative on-demand ridesharing alone (including UAM) will not be able to handle a significant portion of passenger volumes without displacing congestion elsewhere. Moreover, the actual cost of transit from the doorstep to the airport is the prime concern for many passengers and airport workers. Affordable mass transit should be considered as part of any commercial service airport access strategy that aims to tackle congestion. The immediate success of the Silver Line to Washington–Dulles International Airport, which represents about 10% of passenger flows to and from the airport after a few weeks of operations, shows that mass transit is meaningful in areas suffering from acute congestion.

Consequently, the question of innovation in transportation cannot be reduced to its sole technological component. Legacy modes combined with new technologies, including bus, LRT, and cableways, constitute a reservoir of untapped opportunities that can provide efficient and inclusive access to aviation facilities. Furthermore, innovation in airport access can also be conceptual or organizational. Airports and their stakeholders can leverage nontraditional solutions to provide new access options, deliver on equity, and create revenue streams. Therefore, the situation could be summarized by the growing need to fix old problems and meet new expectations with a customized blend of legacy and innovative solutions to provide a holistic response to local issues.

LANDSIDE STRATEGIES FOR ACCOMMODATING MULTIMODALITY

Ultimately, the evolution of airport access has an impact on airport planning and development. All the different users (passengers, aviation and airport professionals, local residents) and modes need to converge at some point, and this can be achieved through multimodal centers that increase interconnectivity, mutualize resources, and improve utilization of space. Furthermore, airports, serving as intermodal nodes, play a crucial role in connecting different transportation modes, catering to the needs of local community members and travelers using mass transit. Some airports have evolved into truly multimodal facilities, hosting diverse transportation modes within their premises. In the future, passengers might come to the airport for connecting between modes that do not include flights and airports would be considered as multiports, envisioning facilities where different modes are seamlessly integrated and fully interconnected. This integrated approach, accommodating various facility operators and transportation modes, fosters a dynamic environment for passengers connecting with diverse services. This diversity of modes leads to a higher demand in space and infrastructure on the landside. At many historical airports, expanding or redeveloping the immediate curbside area might be excessively costly and impactful to ground accessibility. A solution can be to create a reasonably remote GTC connected to the airport by a people mover.

From an operations standpoint, these new modes will have an impact on revenues. The rise of CAVs could deplete airport parking garages. Passengers might ride to the airport using autonomous ridesharing vehicles ordered from their smartphones. The remaining users of personal vehicles may shift to some sort of fractional ownership alternatives. Airports have to anticipate this change that might be more impactful and brutal than the development of transportation network companies. They could consider levying a user fee for future on-request CAV drop-off and pick-up. Existing parking garages could be turned into vertiports, office spaces, or hubs for CAV fleets.

Another requirement for these new modes will be their compatibility with the emerging remote services that will be offered to passengers. For instance, it is possible in many large cities to check bags at a downtown facility before taking a ride to the airport (e.g., Hong Kong, Kuala Lumpur, and Seoul). The practicality of some of these services can be hampered by other aviation-specific needs. In particular, the value proposition of modal options should not adversely affect safety and security.[d]

d From 1956 to 1980, the Silver Arrow rail-air service proposed to passengers between Paris and London to ride by train from Paris to Le Touquet–Côte d'Opale Airport (LTQ) and take a plane from there to cross the Channel. From a period of time, the train was stopping on the apron and passengers could walk straight to their plane. Such seamlessness cannot be achieved today as it might require additional safety and security nets.

CHAPTER 10

SUSTAINABLE AND NET-ZERO AIRPORTS

THE NEGATIVE EXTERNALITIES OF AVIATION

Like any human activity, air transportation has negative externalities. Aircraft noise has been one of the first airport-related environmental issues to be recognized as such. Programs and activities aiming at reducing the number of people affected by noise have had significant effects since the 1970s in several countries (Fig. 31). However, according to ICAO, the footprint of the 55 dB DNL noise contour[a] from 315 commercial service airports representing 80% of the global traffic could double if no progress is made on aircraft technology (Fig. 32). The 2015 footprint represents 14,400 km^2 and 30 million people. Advanced but achievable technological improvement could stabilize this accrued noise exposure to its 2015 level and even reduce it. While the aircraft and engine design industries are working on such improvements, airports and governments also have a strong role to play for reducing this footprint, enhancing the insulation of the most exposed homes, and lowering the number of residents within this contour on the long-term. ICAO's standards and recommended practices (SARPs) on aircraft noise at airports include the framework for aircraft type noise certification expressed in the Assembly Resolution A39-1 of 2016.[338] It also includes the guidance developed through the "Balanced Approach to aircraft noise management" (Doc 9829), which is based on four main levers:

- Reduction at source
- Land use planning and management with policies and guidance[339,340,341]
- Operational improvements such as noise abatement procedures,[342,343] including the Noise Abatement Departure Procedures[344] and continuous descent and climb operations[345,346]
- Operating restrictions, including noise charges on the noisiest aircraft types[347,348]

This Balanced Approach analysis is specific to each airport geography, traffic, and conditions and a social and economic analysis must be undertaken for each measure envisaged.

Aerial pollution (e.g., particulate matters and sulfur oxides) and greenhouse emissions (e.g., carbon dioxide and nitrogen oxide) are the main types of gaseous externalities of an airport (Fig. 33). Airports shall have a holistic vision of these emissions when preparing a sustainable plan. They should include the emissions of aircraft, ground handling services, passenger terminals and support facilities, landside facilities, but also ground transportation from and to the airport for passengers and airport workers, and emissions of their supply chain as well. On the airside, in addition to the tremendous improvements accumulated over the years by the introduction of new aircraft compliant with stringent certification requirements based on ICAO SARPs, the rapid dissemination of electric ground support equipment and the restriction of the use of the auxiliary power unit have the potential to bring the direct emissions of the turnaround process at the gate down to zero. Lower-emission taxiing using electric

[a] The Day-Night average sound Level (Ldn or DNL) is the average noise level over a 24-hour period. The noise level measurements between the hours of 10PM and 7AM are increased by 10 dB before averaging. This noise is weighted to consider the decrease in community background noise of 10 dB during this period.

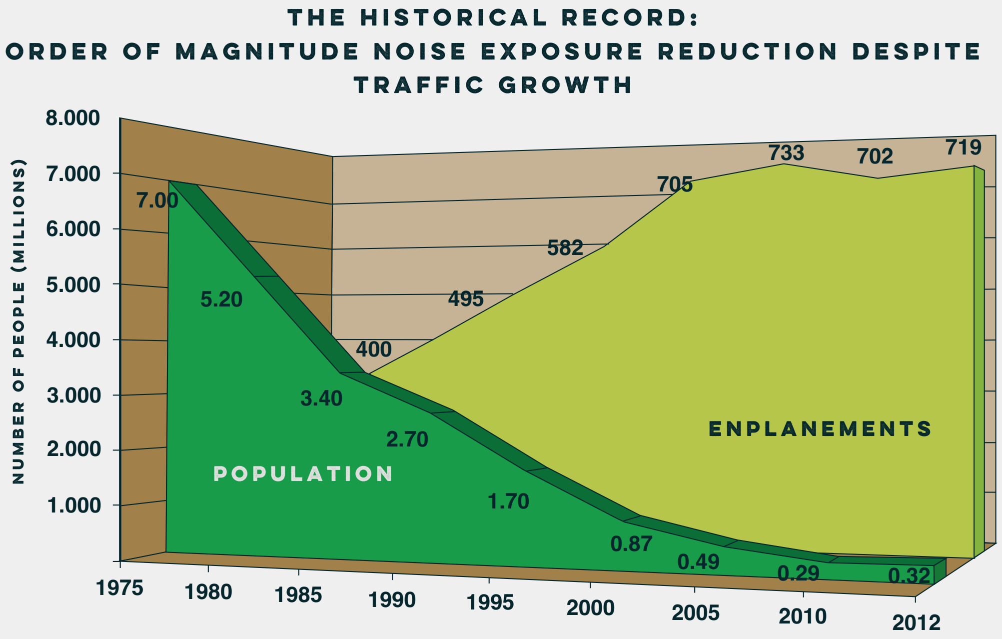


FIGURE 31. EVOLUTION OF THE POPULATION LIVING WITHIN 65 DB DNL CONTOURS IN THE UNITED STATES

Source: U.S. Federal Aviation Administration

and hybrid tow-tractors or onboard systems can reduce emissions from the gate to the runway threshold area. The attractiveness and commercial success of these technologies are highly dependent on the variation of fuel price and their compatibility with existing airport facilities. On the landside, providing and promoting mass transit and greener modes of transportation is an active part of a sustainable plan. Passenger terminal facilities are also major energy consumers and waste producers. Standards, building codes and certifications such as EDGE of the World Green Building Council, Envision and the Leadership in Energy and Environmental Design (LEED) in the United States, the Building Research Establishment Environmental Assessment Method in the United Kingdom, or the Green Building Index in Malaysia lead the way toward greener infrastructure.

Impact on natural spaces have been recognized since the 1970s with one of the first airport environmental studies carried out by the Everglades Jetport project in the United States. The study led to the cancellation of the project due to the significant impact it would have had on the Floridian Everglades. Since then, eco-responsible countries have made environmental impact assessments a legal requirement. Other externalities include water discharges that can be a specific concern during winter operations—salts from pavement deicing and glycols from aircraft deicing. More recently, the awareness of nocturnal artificial light as a public health issue has arisen. Its impact on wildlife has also been documented. Switzerland was one of the first countries to take measures to fight this pollution with recommendations made in 2005 by the Federal Office for Environment that were followed by local and then federal regulations. Other countries and local governments[b] have followed with their own regulatory framework.

b While the U.S. does not have federal regulations on light pollution, nearly 20 of States and territories impose restrictions.

THE VALUE ADDED OF AVIATION TO SOCIETY

Aviation is essential to our modern, globalized economy. Aviation supports most of the 17 Sustainable Development Goals the United Nations set in 2015.[349] Airports make a massive contribution to the economic welfare of regions. They are centers of direct and indirect employment: personnel employed by airport operators directly and by other entities at the airport represent more than 6.1 million jobs globally. Airports initiate large investments for maintaining and developing their infrastructure, leading to additional local jobs. The typical multiplier between direct (airport) and indirect (airport-induced) jobs at an airport is around 2. They require ground infrastructure that will benefit the outer community and the region, such as highways, trains, and utilities. They create revenues being taxed by governments, from additional income tax to value-added tax. Amsterdam Airport Schiphol accounts for about 3% of the Dutch GDP. The larger Schiphol Mainport region generates about 15% of the national GDP. High-quality air service increases the offer. It enables a broad range of opportunities and widens the horizon of possibilities, attracting businesses, residents, and tourists.

Airports create high-speed mobility options between cities, regions, and countries, offering direct connections to the world for manufacturers and investors. Some businesses require aviation to move their workforce to support clients and ship goods to the end users (e.g., pharmaceutical industry, electronic manufacturing services, floral industry). But aviation does not only benefit large corporations. It creates new opportunities for small local producers. The Nuestra Huerta initiative of Mariscal Sucre International Airport in Quito, Ecuador, integrates small farmers to sell their product at the airport. Kenya's booming horticulture industry could not export their products up to the worldwide market of Amsterdam without air freight.

Tourism has been a powerful economic contributor and development driver for many regions and countries all over the world such as the Greater Paris in France, the U.S. state of Florida, Brazilian's Nordeste, as well as Morocco, Mauritius, or Thailand. More than half of the international tourists travel by air.[c] About 90% of tourists visiting Costa Rica arrive in the country by plane. While the country has pledged to shut down mineral extraction, stop deforestation, and focus on more sustainable resources such as responsible tourism, air transportation is a necessity to achieve these goals.

Aviation helps address natural obstacles hindering the freedom of movement. For many insular countries and overseas territories, air transportation is the only mean to move passengers and goods from island to island in a timely manner. Accelerating the development of electric aviation has been acknowledged as beneficial for Nordic citizens as their countries have a rugged topography characterized by fjords and mountains.[350,351] Rwanda, known as the land of a thousand hills, has implemented a network operated with small UAS for supporting its healthcare system. The light fixed-wing aircraft carry pharmaceutical products and medical payloads across the country.

Airports provide mobility to remote or scarcely populated areas. Communities in the Great North, the Caribbean, the Pacific Ocean, and the Amazon forest are delivered

c 57% in 2017 according to the 2018 Aviation Benefits Beyond Borders of Air Transport Action Group (ATAG).

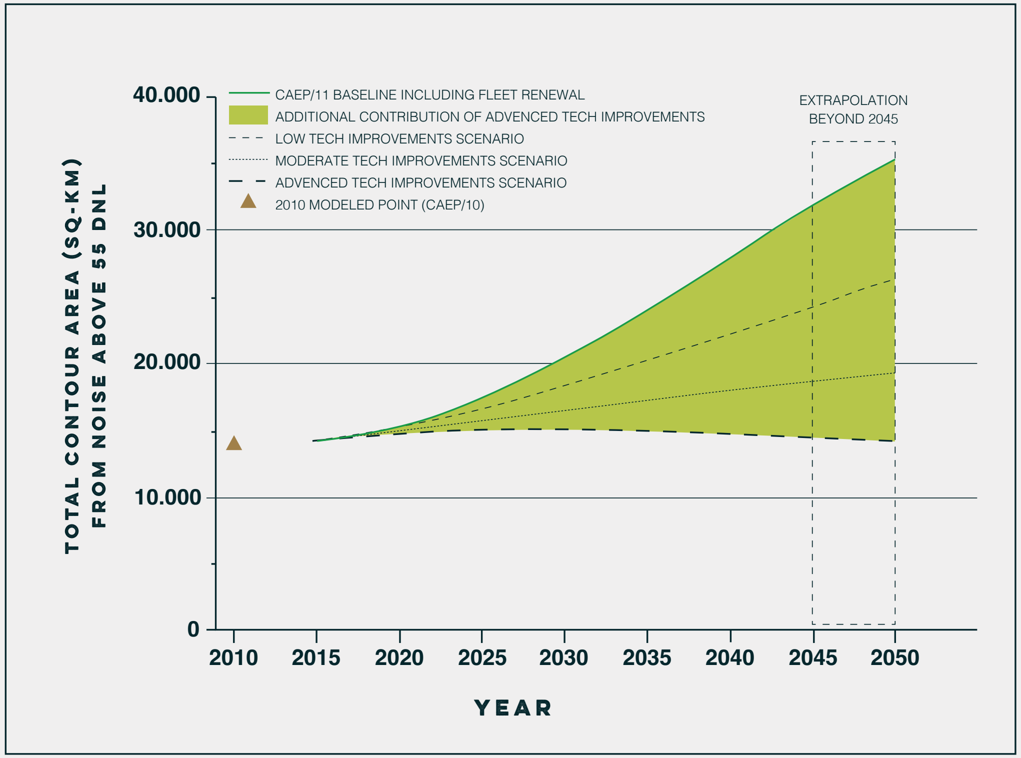


FIGURE 32. TOTAL AIRCRAFT NOISE CONTOUR AREA ABOVE 55 DB DNL FOR 315 AIRPORTS (2010–2050)

Source: ICAO

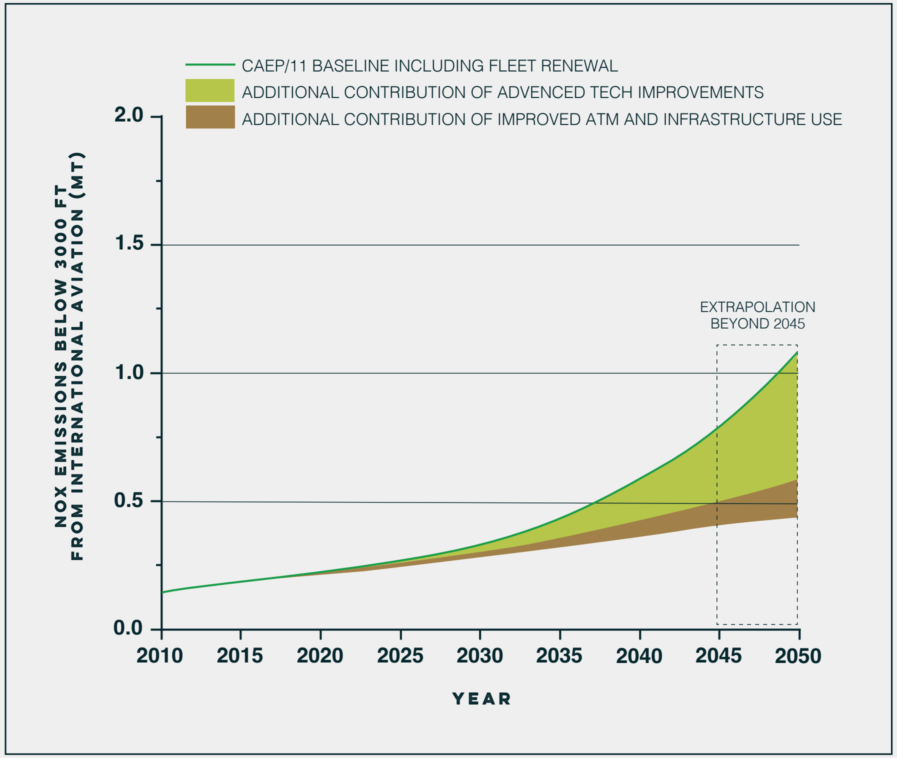


FIGURE 33. AIRCRAFT NITRIC OXIDE EMISSIONS BELOW 3,000 FEET FROM INTERNATIONAL AVIATION (2010–2050)

Source: ICAO

with essential goods and services (freight and mail), have access to education and health services, and can move long-range by plane only. Juneau, the capital city of Alaska, is not served by any road. Traveling between major Andean cities can take days by roads that do not always meet the international practices on roadway safety. Aviation is also vital to the Navajo Nation, which operates its own system of airports for enabling medical evacuations and other services. Humanitarian aid and search and rescue missions need aviation facilities to support their operations as well. In remote areas and across vast territories, connectivity provided by air transport can be more sustainable than if ground infrastructure were built–assuming it is even realistically achievable and desirable.

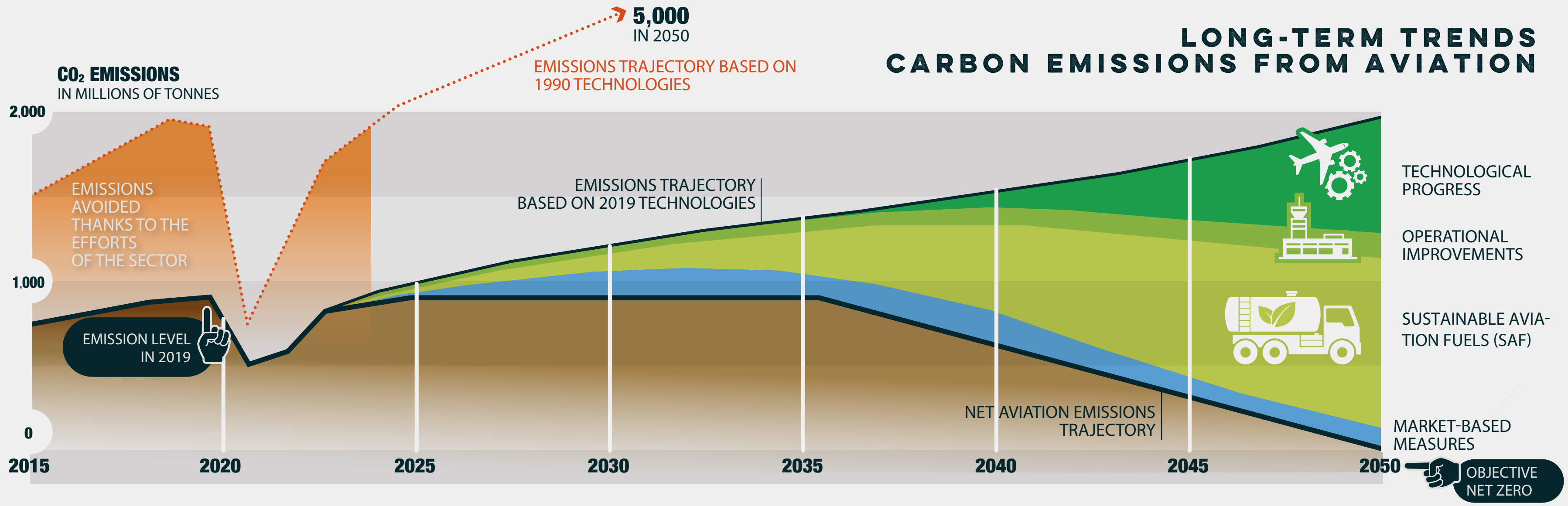
TOWARD A NET-ZERO AVIATION BY 2050

The impacts of climate change on airports and aviation as a whole have been taken into consideration for decades.[352] Aviation accounts for about 2% of the worldwide carbon dioxide emissions, a constant share since the early 1990s, even if the absolute emissions regularly increase due to the growing demand for air travel. Although carbon dioxide is the GHG significantly emitted by aviation, other pollutants (e.g., sulfur oxide, particulate matter) are also emitted. Part of these emissions occur at high altitudes, which might increase their net impact according to models. However, there is still an uncertainty on the exact direct contribution of aviation to climate change. For instance, aviation nitric oxide emissions contribute to ozone generation (increasing the greenhouse effect) under certain conditions, and to methane depletion at other altitudes (reducing this same effect). Also, the impact of contrails and their ability to generate cirrus clouds have to be taken into consideration and be mitigated.[353]

This impact should be approached in a holistic way. For instance, comparisons between modes should take into consideration the carbon emitted by the construction and maintenance of the infrastructure, the production and procurement of the materials, and the real emissions of the trip itself–including emissions due to the electricity production for electric trains for instance. It should also include the other environmental impacts of the whole transportation system—e.g., modification of natural spaces and urban/rural discontinuity created by linear ground transportation systems. Modes should also be compared with what they provide. The value of time and the final mobility service should be considered in the context of aviation's commitment

FIGURE 34. LONG-TERM EVOLUTION OF NET CARBON DIOXIDE EMISSIONS FROM CIVIL AVIATION

Source: ATAG, ICAO, U.S. FAA



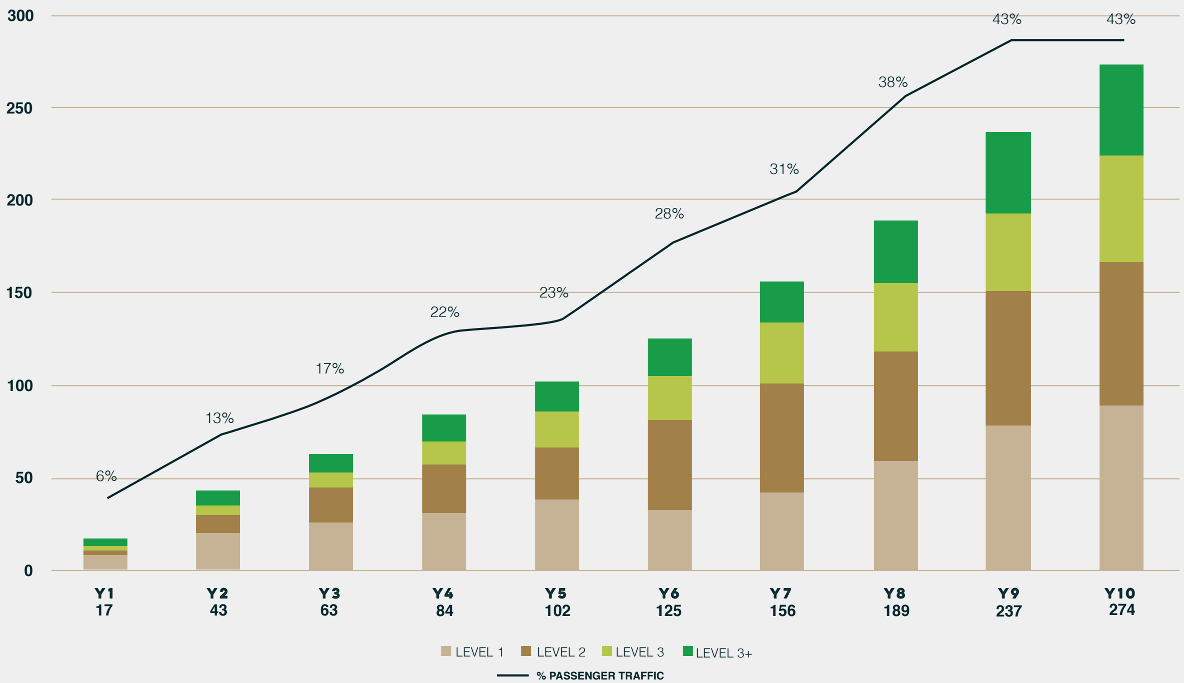


FIGURE 35. AIRPORTS CARBON ACCREDITATION PROGRAM (2009-2018)

Source: Airports Council International

to achieve net-zero emissions by 2050 (Fig. 34).[d]

The Airport Carbon Accreditation program of ACI World is a global carbon management initiative that specifically targets airport emissions.[e] The initiative provides a framework for airports to reduce their carbon footprint through local green initiatives as well as carbon offsetting in an objective to carbon neutrality. To apply for certification at one of the different levels of the program, airports must have their carbon footprints independently verified in accordance with ISO14064 (Greenhouse Gas Accounting). Evidence of this must be provided to the administrator together with all claims regarding carbon management processes, which must also be independently verified. The definitions of emissions footprints used by Airport Carbon Accreditation follow the principles of the World Business Council for Sustainable Development and the World Resources Institute "Greenhouse Gas Protocol" Corporate Accounting and Reporting Standard, the reference in GHG accounting and reporting. When considering the emissions from aircraft within the airport perimeter and on final approach and initial departure, Airport Carbon Accreditation uses the ICAO definition of the landing-take off cycle and requires airports to comply with these definitions. As of 2024, 557 airports are accredited (Fig. 35). They account for more than half of the global traffic. Among them, 124 airports around the world are certified at least Level 3+. The ACI Europe members pledged in 2017 to become carbon neutral by 2030. Over 20 airport management companies have signed this commitment.

The Airport Carbon Accreditation and carbon offset as a way to reduce the footprint of individual airports should not be underestimated, and neither should the ICAO's Carbon Offsetting and Reduction

d For instance, long-range, transoceanic flights cannot be compared to light-rail.

e Aircraft emissions are not included in the program.

Scheme for International Aviation (CORSIA).[354,355] At the same time, it is just a first step toward greener airports. Comprehensive decarbonization of airports will require the reduction and, as far as practicable, the elimination of emissions at the source. This includes local ordinances banning excessively emitting solutions when lower-emission alternatives are available (such as the use of the APU at the gate when 400Hz blocks are provided) or incentives to encourage the transition to lower-emission technologies such as VALE in the United States. Avinor at Oslo Airport and Port of Seattle at SeaTac Airport have contributed to the implementation of SAF. Per CORSIA, SAF must be produced from sustainable biomass sources harvested from land whose uses changed after January 1, 2008. The first fuel standards were approved in 2009. SAF can be blended with fossil fuels and delivered via existing fueling systems. Electric aviation has a potential of further decarbonization, especially for the general aviation and for short-haul, commuter traffic starting over the coming decade. In Norway, Avinor is leading a national roadmap on the development of electric aviation. London Heathrow is committed to exempt e-aircraft from landing fees. A massive move to electric aviation should be part of a broader vision for a virtuous electric economy. The electricity used for charging aircraft batteries should be itself low-emission, including the supply chain, and the batteries should have a virtuous life cycle, which might have yet to be developed.

Finally, airports are also stricken by the effects of climate change.[f] In addition, it has several indirect effects in relation to sustainability and corporate responsibility. For instance, in some areas, climate gentrification, where the move of higher-income households to areas protected from climate-related events drive a rapid increase of home values and rents, might push lower-income households to consider airports' vicinity. Also, climate change will adversely impact the attractiveness of entire regions, and sometimes wipe out natural treasures and leisure activities inducing a loss of revenues—including for airports. It is in the interest of the airport industry to reduce its carbon footprint and work collaboratively with their communities on climate resilience. In 2009 and then 2021, the global aviation industry committed to achieve net-zero carbon emissions through three main levers:

1. Improve fleet fuel efficiency by 1.5% per annum between 2009 and 2020. A drop of 2.1% per year was achieved over that period.

2. Cap net carbon emissions from international aviation through carbon-neutral growth beginning in 2020. This is being achieved with the implementation of CORSIA, as part of the Basket of Measures defined by ICAO.[356]

3. Achieve net-zero emissions by 2050. The massive introduction of SAF will contribute to this objective.

The ICAO member states support this goal through a long-term aspirational goal signed in 2022.

f The direct effects are specifically explored in Chapter 8: Operational Performance and Resilience.

AVIATION SHALL PAY FOR ITSELF AND ITS FUTURE

In the recent years, several countries (e.g., France and Germany) have passed or considered passing laws establishing green taxes (also known as eco-taxes) on aviation. Some have declared they will use the funds collected through these taxes to finance or subsidize non-aviation projects, which could include support to highway and railway projects. Diverting profits from one mode to give to another is a disturbing move that is not necessarily greener and could create competition distortion especially because rail and road transportation have been progressively privatized. Finally, this is sending a negative message to aviation that should not be used as a band-aid to the general budget of governments. Furthermore, taxing airlines will reduce their financial ability to renew their fleet with more efficient, greener aircraft.

Such unilateral decisions miss the opportunity to make a bold political statement and create an impetus. Aviation eco-taxes should be used as incentives to aviation pursue further in that direction and reward the efforts made for a lower-emission aviation. In the United States, a popular expression is that "aviation shall pay for itself." This has been the successful driver of the development of the U.S. aviation system since after World War II. This motto should be applied worldwide.

CHAPTER 11

HUMAN RESOURCES AND EDUCATION

THE WORLD CHANGES AND THE WORKPLACE AS WELL

Most of the job descriptions of 2040 and 2070 will include requirements and missions that do not exist today and may not even be imaginable. Airports had no social media managers or SMS specialists 20 years ago, but these are essential roles in modern airports. Technology is a big driver as well. For instance, the implementation of geographic information systems (GIS) created new jobs. GIS has proven itself to be an invaluable tool for others with applications ranging from asset management to aeronautical information.

The workplace itself is changing. Many tasks can now be performed from remote locations with the same or higher productivity. Virtual meeting rooms, cloud-based document management, work file sharing solutions, and workflow management software are among the tools that can power agile organizations enabling remote work. These tools allow employees to work on different projects and sites. They open the door to a better work-life balance without compromising efficiency. This revolution will impact operational jobs as well. It already did it. For instance, ground handling operations are now supervised from hub control centers at several airports. Construction supervisors can be virtually present on a project site. Security perimeters can be inspected from a control center via automated vehicles and sensors. However, teams in the field will be needed to resolve complex tasks where the machine is not proficient enough, or where direct human interactions are required or preferred due to social choices and cultural acceptance. The most recent APOC are good examples of this collaborative work between managers and coordinators physically based at the APOC facility. They work with systems and sensors, reporting to, alerting, and assisting to decision-making. Teams in the field are the arms of this organization to directly interact with the airport environment.

Humans are social animals. They need to gather and share together. Well-being at work and a collaboration environment are keys to performance and efficiency. Being a “great place to work” is also important to attract and retain talents. Workers are increasingly giving importance to the values of their organization, the meaning of their work, the interaction with their management, the collaboration with their teammates and stakeholders, and the flexibility they can have in managing their daily routine. Studies show that younger workers prefer having the option to work from home. But, at the same time, they want a higher level of interaction with their coworkers and their management. The future cannot be system centric; it must be human-centric, with more freedom and flexibility. Systems can help us interact with each other and advance at a faster pace.

CHANGE AND KNOWLEDGE MANAGEMENT WILL BE PART OF REGULAR OPERATIONS

As new technology appears and the succession of innovational breakthroughs accelerates, airports will need a new approach to change and knowledge management. Technological shocks similar to the first IT revolution, which required generations to learn and transition to computers and information systems, will be more frequent. Freshly graduated young professionals might already have to start learning new vital skills shortly after leaving school. Organizations might have to adapt as well. Change management will be part of regular operations.

Successful airports will identify these emerging changes early, evaluate their effects on existing conditions, and adapt their organization and train their staff. It would not be surprising to have full-time change manager positions at many airport and stakeholder organizations.

Another "IT" revolution is in the making with the advent of intelligent technologies. Society is at the threshold of the introduction of AI and ML on a large scale. Thinking about this second IT revolution as a modification of the way people interact with existing electronic devices and systems is missing the point. Intelligent systems will open a broad field of completely new applications that industry professionals can barely envision as of today. Some of them will assist human operators. Some others might even replace human decision-makers. Intelligent systems will create new needs for specialists able to develop and maintain these systems, make sure they interact adequately, and interpret their output—such as what-if scenarios—for final decision-making. AI will deeply change our interactions with our world, including the way we move, communicate, enjoy, consume, and work.

A NEW GOLD RUSH TO SKILLED WORKERS AND SUBJECT MATTER EXPERTS

As a consequence of these changes, there will be a growing need for continuing education to align skills to needs. Major firms have created e-learning hubs accessible to their employees from their computers, and this mode of acquiring new skills will become increasingly widespread and organized. Airport training centers—such as the Dubai Airport Launchpad, or the Universidade Infraero—are emerging as well for fostering mutual learning across the internal and external stakeholders. Some of these programs might be developed in partnership with legacy aviation colleges to connect these new knowledges to the forefront of the research. Smaller airports will most likely outsource to specialized continuing education firms or utilize the resource of larger airports, raising the question of the financial burden of such a challenge. Mutualization and support from professional organizations, such as the American Association of Airport Executives in the United States, are already proven to be an effective way to address this with training solutions such as the Airport Certified Employee programs[357] or the C2FPA in France with programs and facilities for airport firefighters.[a]

Few universities in the world offer airport-specific programs to prepare the industry leaders of tomorrow. Remote learning and continuing education might fill part of the gap. However, some of the new skills that airports and their stakeholders will need at the 2040 and 2070 horizons might be so technically specific and out of their core business that outsourcing will be evident especially at smaller facilities. Most of the airport operators and aviation administrations will not be able to recruit and retain highly specialized experts able to master new critical tasks out of these core missions. Specialized firms and their subject matter experts will compete for providing the needed services. It is vital for the success of these collaborations that these experts do not miss the specificities of airports. Aviation itself is an expertise, and

a C2FPA was founded in 2007 by a coalition of airports and The French-Speaking Airports association (UAF&FA). The ownership was transferred to the private firm Groupe 3S later on.

moderators educated in aviation might be needed for helping future experts in these new technologies and processes to understand the needs of their aviation clients.

LET US CLOSE THE GAPS AND GET RID OF BIASES ONCE FOR ALL

Gender-based discrimination alone costs up to $12 trillion for the global economy—16% of the global income. Women are historically underrepresented among the transportation workforce, and victim of biases during their career. Only 3% of the CEOs of the aviation industry are women, compared to 6.5% of all the Fortune 500 CEOs, shocking considering that 49.6% of humans are females. However, pioneers have led the way for the next generations, and airport organizations are changing as well. Prominent female airport leaders among the top 10 busiest airports and major institutions have included Angela Gittens who led ACI World and the Atlanta and Miami airports; Jamie Rhee, Commissioner of the Chicago Department of Aviation; Matrice Ellis-Kirk, Chair of the Board of Directors of Dallas–Fort Worth Airport; and Deborah Ale Flint, President and Chief Executive Officer (CEO) of Greater Toronto Airport Authority and former CEO of Los Angeles World Airports.

Organizations must reflect the diversity of their clients and communities to remain competitive and innovative. A diverse workforce and management are crucial for embracing and addressing the complexity of the challenges to come. Diversity is not limited to gender and ethnicity. It includes (and is not limited to) age, sexual orientation, socio-economic status, disabilities, and cognitive diversity. Studies have shown the clear benefits of diversity and inclusion in organizations. Organizations with a diverse workforce are significantly more likely to achieve above-average financial returns.[358] Firms with a diverse management team generate 19% more innovation revenue than those with average or lower levels of diversity.[359] Many leading airports now have a top executive manager in charge of ensuring diversity and equity and specific programs for fostering these values in their recruitment. However, they must also ensure inclusion, with a workplace environment promoting fairness and mutual respect and assuring equal opportunities for everyone. Airports and their stakeholders should not be alone in this journey. They should ensure that their contractors and their supply chain embrace the same values and effectively implement diversity and inclusion programs.

While the 20th century fell short in delivering expectations of freedom, justice, and progress for all, the 21st century must not follow the same path. The world cannot afford discrimination and biases. It is not only a question of fairness, but a matter of resilience of society as resources become scarce. Discrimination does not only go against the very fundamental values of aviation that were expressed at the Chicago Convention on International Civil Aviation and are reflected in our diverse clients and workforces.[b, 360] Discrimination prevent talent from emerging, innovation from blooming, and opportunities from coming true. To address the challenges of 2040 and 2070, the aviation industry must close these gaps and eliminate biases once for all.

b The Preamble specifies that “the future development of international civil aviation can greatly help to create and preserve friendship and understanding among the nations and peoples of the world”.

ABBREVIATIONS

AAI	Airports Authority of India
AAJ	Airport Authority of Jamaica
AAM	Advanced Air Mobility
ACAC	Airport Construction Advisory Council
A-CDM	Airport Collaborative Decision Making
ACI	Airport Council International
ACRP	Airport Cooperative Research Program
ACSA	Airports Company South Africa
ADAC	Abu Dhabi Airport Company
ADM	Aéroports de Montréal
ADR	Aeroporti di Roma
AENA	Aeropuertos Españoles y Navegación Aérea
AFIS	Aerodrome Flight Information Service
AGIS	Airport Geographical Information Systems
AHA	Aviation Hazard Areas
AI	Artificial Intelligence
AMS	Amsterdam Airport Schiphol
ANAC	Agência Nacional de Aviação Civil (Brazil)
ANN	Artificial Neural Network
ANSP	Air Navigation Service Provider
AOP	Airport Operations Plan
APOC	Airport Operations Center
APM	Airport People Mover
ARIWS	Autonomous Runway Incursion Warning System
ASEAN-SAM	ASEAN Single Aviation Market
ASUR	Grupo Aeroportuario del Sureste, S.A.B. de C.V.
ATAG	Air Transport Action Group
ATC	Air Traffic Control
ATCT	Air Traffic Control Tower

ATCo	Air Traffic Controller
ATL	Hartsfield-Jackson Atlanta International Airport
ATM	Air Traffic Management
BCB	Body Cavity Bomb
BIM	Building Information Modeling
BKG	Branson Airport
BNDES	Banco Nacional de Desenvolvimento Econômico e Social
BOT	Built-Operate-Transfer
BVLOS	Beyond the Visual Line of Sight
CAAC	Civil Aviation Administration of China
CAAMS	China's Strategy for Modernizing Air Traffic Management
CAG	Changi Airport Group
CAGR	Compound Annual Growth Rate
CAH	Capital Airport Holding
CAV	Connected and Automated Vehicle
CDG	Paris-Charles de Gaulle Airport
CDM	Collaborative Decision Making
CNS	Communication, Navigation and Surveillance
ConOps	Concepts of Operations
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
CTOL	Conventional Takeoff and Landing
DAC	Dubai Airports Company
DAESP	Departamento Aeroviário do Estado de São Paulo
dB	Decibel
DBO	Design-Build-Operate
DECEA	Departamento de Controle do Espaço Aéreo (FAB)
DFW	Dallas-Fort Worth International Airport

DGAC	Direction Générale de l'Aviation Civile (France)
DVE	Domestic Violent Extremist
EASA	European Aviation Safety Agency
ECAA	European Common Aviation Area
EGSA	Etablissement de Gestion de Services Aéroportuaires
EHCAAN	Egyptian Holding Company for Airports and Air Navigation
EHPS	Electric and Hybrid Propulsions Systems
EIB	European Investment Bank
EMI	Electromagnetic Impulse
ENAC	Ecole Nationale de l'Aviation Civile
ENANA-EP	Empresa Nacional de Exploração de Aeroportos e Navegação Aérea E.P.
ENSO	El Niño–Southern Oscillation
ERAU	Embry-Riddle Aeronautical University
FAA	U.S. Federal Aviation Administration
FAB	Força Aérea Brasileira
FAB	Functional Airspace Block
FATO	Final Approach and Takeoff Area
FIT	Florida Institute of Technology
GACA	General Authority of Civil Aviation
GANP	Global Air Navigation Plan
GASeP	Global Aviation Security Plan
GASP	Global Aviation Safety Plan
GDP	Gross Domestic Product
GMF	Global Market Forecast
GMR Group	Grandhi Mallikarjuna Rao Group
GPS	Global Positioning System
GRU	GRU Airport / São Paulo/Guarulhos–Gov. André Franco Montoro Intl. Airport
GSE	Ground Service Equipment
GTC	Ground Transportation Center
HCC	Hub Control Center

HKG	Hong Kong International Airport
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
Infraero	Empresa Brasileira de Infraestrutura Aeroportuária
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
JFK	John F. Kennedy International Airport
LAC	Latin American and Caribbean
LAMP	Landside Access Modernization Program
LAWA	Los Angeles Airport World
LAX	Los Angeles International Airport
LCY	London City Airport
LGA	New York LaGuardia Airport
LGP	LaGuardia Gateway Partners
LGW	London Gatwick Airport
LHR	London-Heathrow
MaaS	Mobility as a Service
MANPAD	Man-Portable Air-Defense System
MDAD	Miami-Dade Aviation Department
META-CDM	Multimodal, Efficient Transportation in Airports and CDM
MIA	Miami International Airport
ML	Machine Learning
MRS	Marseille-Provence International Airport
MWAA	Metropolitan Washington Airports Authority
NEXTT	New Experience Travel Technologies
NFC	Near-Field Communication
NM	Network Manager
NOAA	U.S. National Oceanic and Atmospheric Administration
O&C	Ownership & Control

OCC	Operations Control Center
OER	Örnsköldsvik Airport
OEM	Original Equipment Manufacturer
ONDA	Office National Des Aéroports
ORD	Chicago-O'Hare International Airport
ORY	Paris-Orly International Airport
PANYNJ	Port Authority of New York and New Jersey
PARAFE	Passage Automatisé Rapide Aux Frontières Extérieures (France)
PHL	Philadelphia International Airport
PPP	Public-Private Partnership
PKX	Beijing Daxing International Airport
PRT	Personal Rapid Transit
PtL	Power-to-liquid
RAM	Rural (or Regional) Air Mobility
RESA	Runway End Safety Area
RIPS	Runway Incursion Prevention System
RIPSA	Runway Incursion Prevention through Situational Awareness
RIRP	Runway Incursion Reduction Program
ROAAS	Runway Overrun Awareness and Alerting System
ROPS	Runway Overrun Prevention System
RPA	Regional Plan Association
RPK	Revenue Passenger Kilometer
RPZ	Runway Protection Zone
RTC	Remote Tower Center
rTWR	Remote Tower
RVA	Régie des Voies Aériennes de la République Démocratique du Congo
SAAS	San Antonio Airport System
SAATM	Single African Air Transport Market
SAC	Secretaria de Aviação Civil (Brazil)

SAF	Sustainable Aviation Fuels
SAM	Surface-to-Air Missile
SAN	San Diego International Airport
SARP	Standards and Recommended Practices
SDI	Space Data Integrator
SDL	Sundsvall–Timrå Airport
SDU	Rio de Janeiro-Santos Dumont Airport
SESAR	Single European Sky Air traffic management Research
SFB	Orlando Sanford International Airport
SFO	San Francisco International Airport
SIIED	Surgically Implanted Improvised Explosive Device
SJU	San Juan Luis Muñoz Marín International Airport
SMS	Safety Management System
SNCF	Société Nationale des Chemins de Fer Français (France)
SSP	State Safety Program
STOL	Short Takeoff and Landing
SWIM	System Wide Information Management
TAM	Total Airport Management
TIP	Tripoli International Airport
TNC	Transportation Network Companies
TOBT	Target Off-Block Time
TOSC	Technical, Operations & Safety Committee
TRB	Transportation Research Board
TRT	Turnaround Time
TSA	Transportation Security Administration
UAF&FA	Union des Aéroports Français & Francophones Associés
UAM	Urban Air Mobility
UATM	Urban Air Traffic Management
UAS	Uncrewed Aerial System

USOAP	Universal Safety Oversight Audit Programme
UTM	Uncrewed Traffic Management
VCE	Venice Marco Polo Airport
VTOL	Vertical and Take-Off Landing
xTM	Extensible Traffic Management

REFERENCES

1 Department of Economic and Social Affairs, Population Division, United Nations. (2022). *World Population Prospects: The 2022 Revision*. https://population.un.org/wpp/

2 Kharas, H. and Hamel, K. (2018). *A global tipping point: Half of the world is now middle class or wealthier*. The Brookings Institution. https://www.brookings.edu/articles/a-global-tipping-point-half-the-world-is-now-middle-class-or-wealthier/

3 Lu, M. (2023). *113 Million People Will Join the Global Middle Class in 2024. Visual Capitalist*. https://www.visualcapitalist.com/113-million-people-middle-class-2024/

4 Airbus. (2019). *Demand for air travel*. In Global Market Forecast: Cities, Airports & Aircraft 2019-2038 (pp. 12-23).

5 Boeing. (2019). *Commercial Aviation Market Dynamics*. In Commercial Market Outlook 2019-2038 (pp. 4-6).

6 ICAO. (2023). *Effects of Novel Coronavirus (COVID-19) on Civil Aviation: Economic Impact Analysis*. https://www.icao.int/sustainability/Documents/COVID-19/ICAO_Coronavirus_Econ_Impact.pdf

7 ACI-NA. (2023). *Latest air travel outlook reveals 2024 to be a milestone for global passenger traffic*. https://aci.aero/2023/09/27/latest-air-travel-outlook-reveals-2024-to-be-a-milestone-for-global-passenger-traffic/

8 IATA. (2023). *Global Outlook for Air Transport: Highly Resilient, Less Robust* (p. 15). https://www.iata.org/en/iata-repository/publications/economic-reports/global-outlook-for-air-transport----june-2023/

9 Yi, Y. (2018). *China needs 216 new airports by 2035: report*. Xinhua. http://www.xinhuanet.com/english/2018-12/11/c_137665637.htm

10 South China Morning Post. (2023). *India plans US$12 billion splurge on 72 new airports by 2025*.

https://www.scmp.com/news/asia/south-asia/article/3214125/india-plans-us12-billion-splurge-72-new-airports-2025

11 Agenzia Nova. (2023). *Brazil announces studies for the construction and renovation of one hundred airports*.

https://www.agenzianova.com/en/news/Brazil-announces-studies-for-the-construction-and-renovation-of-one-hundred-airports/

12 von Einsiedel, S., et al. (2017). *Civil War Trends and the Changing Nature of Armed Conflict*. United Nations University Centre for Policy Research, Occasional Paper 10, New York. NY. USA. https://collections.unu.edu/eserv/UNU:6156/Civil_war_trends_UPDATED.pdf

13 Dupuy, K., et al. (2017). *Trends in Armed Conflict, 1946-2016*. Center for Security Studies, ETH Zurich, Switzerland.

14 van Zanden, J. L., et al. (2014). *How Was Life? Global Well-being since 1820*. OECD Publishing, Paris.

15 van Zanden, J. L., et al. (2021). *How Was Life? Volume II: New Perspectives on Well-being and Global Inequality since 1820*. OECD Publishing, Paris.

16 Kharas, H. and Dooley, M. (2022). *The evolution of global poverty, 1990-2030*. Brookings Global Working Paper #166. The Brookings Institution. https://www.brookings.edu/wp-content/uploads/2022/02/Evolution-of-global-poverty.pdf

17 UN IGME. (2024). *Levels and Trends Child Mortality - Report 2023 : Estimates Developed by the United Nations Inter-agency Group for Child Mortality Estimation*. http://documents.worldbank.org/curated/en/099606103132489570/IDU1fbafa94215bd114a6519154160cebfe26c8b

18 Nord, M. et al. (2024). *Democracy Report 2024: Democracy Winning and Losing at the Ballot*. University of Gothenburg: V-Dem Institute. https://v-dem.net/documents/44/v-dem_dr2024_highres.pdf

19 Salmeron-Gomez, D. et al. (2023). *Global Trends in Child Monetary Poverty According to International Poverty Lines*. Policy Research Working Paper 10525. World Bank Group. https://www.unicef.org/media/146771/file/Global%20Trends%20in%20Child%20Monetary%20Poverty:%20According%20to%20International%20Poverty%20Lines.pdf

20 EIU. (2024). *Democracy Index 2023: Age of conflict.* The Economist Intelligence Unit.

21 AUDA-NEPAD. (2022). *Second Continental Report on the Implementation of Agenda 2063.* African Union, Johannesburg. https://au.int/sites/default/files/documents/41480-doc-2nd_Continental_Progress_Report_on_Agenda_2063_English.pdf

22 Times Aerospace. (2023). *AFRAA AGM: Liberalised market via SAATM is a slow process.* https://www.timesaerospace.aero/news/air-transport/afraa-agm-liberalised-market-via-saatm-is-a-slow-process

23 Ngumba, A., & Karita, M. (2018). *Single African Air Transport Market – Is Africa ready?* Deloitte. https://www.deloitte.com/content/dam/assets-zone1/ke/en/docs/industries/consumer/2023/ea-SAATM-aviation-report-2018.pdf

24 Law N° 13.842 of June 17, 2019 modifying Law nº 7.565 of December 19, 1986 (Código Brasileiro de Aeronáutica). Pub. in the DOU of June 17, 2019. Extra Edition. Section 1. Brasília, Brazil.

25 Agência Nacional de Aviação Civil. (2019). *ANAC aprova concessão da Globalia Linhas Aéreas.* https://www.anac.gov.br/noticias/2019/anac-aprova-concessao-da-empresa-air-europa-no-brasil

26 UN Department of Economic and Social Affairs. (2018). *World Urbanization Prospects: The 2018 Revision.*

27 U.S. Census Bureau. (2022). *Nation's urban and rural populations shift following 2020 Census.* https://www.census.gov/newsroom/press-releases/2022/urban-rural-populations.html

28 Regional Plan Association. *Megaregions.* America 2050. http://www.america2050.org/content/megaregions.html

29 Frey, W. H. (2023). *Pandemic-driven population declines in large urban areas are slowing or reversing, latest census data shows.* Brookings. https://www.brookings.edu/articles/pandemic-driven-population-declines-in-large-urban-areas-are-slowing-or-reversing-latest-census-data-shows/

30 Hoornweg, D. & Pope, K. (2014). *Socioeconomic Pathways and Regional - Distribution of the World's 101 Largest Cities.* Working Paper No. 04. Global Cities Institute. Toronto, ON, Canada.

31 Stoker, P. et al. (2021). Planning and Development Challenges in Western Gateway Communities. *Journal of the American Planning Association*, 87(1), 21–33. https://doi.org/10.1080/01944363.2020.1791728

32 Embraer. (2024). Market Outlook 2023. https://www.embraercommercialaviation.com/marketoutlook/

33 Zhou, X. et al. (2024). Go for Economic Transformation and Development in China: Financial Development, Higher Education, and Green Technology Evolution. *Evaluation Review*, 48(1), 32-62. https://doi.org/10.1177/0193841X231166741

34 Yves, M. (2019). *Recyclers Cringe as Southeast Asia Says It's Sick of the West's Trash.* The New York Times. Section B. https://www.nytimes.com/2019/06/07/world/asia/asia-trash.html

35 Chinho, L. et al. (2023). Impact of China's National Sword Policy on waste import:A difference-in-differences approach. *Economic Analysis and Policy*, vol. 78, pp. 887-903. https://doi.org/10.1016/j.eap.2023.04.033

36 Revelle, R. and Suess, H. S. (1957). Carbon Dioxide Exchange between Atmosphere and Ocean and the Question of an Increase of Atmospheric CO_2 During the Past Decades. *Tellus*, 9, pp. 18–27. https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.2153-3490.1957.tb01849.x

37 IPCC. (2018). *Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C approved by governments.* United Nations. Geneva, Switzerland.

38 United Nations Environment Programme. (2018). *Emissions Gap Report 2018.* Nairobi, Kenya.

39 United Nations. (2016). *Report of the Conference of the Parties on its twenty-first session.* Held in Paris from 30 November to 13 December 2015. Addendum. Part two: Action taken by the Conference of the Parties at its twenty-first session. FCCC/CP/2015/10/Add.1.

40 IATA. (2019). *The Impact of Climate Change on Aviation.* Presented at the Safety and Flight Ops Conference. San Francisco, CA, USA.

41 National Academies. (2013). *Anticipating Surprises.* Abrupt Impacts of Climate Change. Washington, DC, USA.

42 ATAG. (2021). *Waypoint 2050.* 2nd Edition. https://aviationbenefits.org/media/167417/w2050_v2021_27sept_full.pdf

43 ICAO. (n.d.). *Resolution A41-21: Consolidated statement of continuing ICAO policies and practices related to environmental protection — Climate change.* https://www.icao.int/environmental-protection/Pages/LTAG.aspx

44 ACI Europe. (n.d.). *Airport Carbon Accreditation.* https://www.airportcarbonaccreditation.org/

45 Vreni, R. et al. (2022). The substitution of short-haul flights with rail services in German air travel markets: A quantitative analysis. *Case Studies on Transport Policy*, 10(4), 99. 2025–2043. https://doi.org/10.1016/j.cstp.2022.09.001

46 EUROCONTROL. (2021). Plane and train: Getting the balance right. Aviation Sustainability Unit: Think Paper #11. https://www.eurocontrol.int/publication/eurocontrol-think-paper-11-plane-and-train-getting-balance-right

47 Dobruszkes, F., Mattioli, G., and Mathieu, L. (2022). Banning super short-haul flights: Environmental evidence or political turbulence? *Journal of Transport Geography*. Volume 104. https://www.sciencedirect.com/science/article/pii/S0966692322001806

48 UN Department of Economic and Social Affairs. (2023). *Leaving No One Behind In An Ageing World: World Social Report 2023.* https://www.un.org/development/desa/dspd/wp-content/uploads/sites/22/2023/01/2023wsr-fullreport.pdf

49 Osamu, S. (2021). *Measures to Address Japan's Aging Society*. Government of Japan. https://www.gov-online.go.jp/eng/publicity/book/hlj/html/202102/202102_09_en.html

50 Wright, J. (January 9, 2023). Inside Japan's long experiment in automating elder care. *MIT Technology Review*. https://www.technologyreview.com/2023/01/09/1065135/japan-automating-eldercare-robots/

51 Funk, A. et al. (2023). Freedom on the Net 2023: The Repressive Power of Artificial Intelligence. Freedom House. https://freedomhouse.org/sites/default/files/2023-11/FOTN2023Final.pdf

52 IATA. (2018). *2018 Highlights*: *IATA Global Passenger Survey.* Montreal, QC, Canada.

53 Howell, S. T. (2023). *All Clear for Takeoff: Evidence from Airports on the Effects of Infrastructure Privatization.* Working Paper 30544. National Bureau of Economic Research, Cambridge MA, United States, 2022. https://www.nber.org/papers/w30544

54 Graham, P. A. (2020). Airport privatisation: A successful journey? *Journal of Air Transport Management*, 89. https://doi.org/10.1016/j.jairtraman.2020.101930

55 Puentes, R., & Lewis, P. (2022). Airport Privatization in the United States. In Competitive Government: Public Private Partnerships (pp. 69–84). Springer. https://doi.org/10.1007/978-3-030-83484-5_5

56 Camila, B. (July 15, 2021). Governo de São Paulo concede 22 aeroportos regionais em leilão. Agência Brasil. https://agenciabrasil.ebc.com.br/economia/noticia/2021-07/governo-de-sao-paulo-concede-22-aeroportos-regionais-em-leilao

57 Alaska Department of Transportation & Public Facilities, Division of Statewide Aviation. (2021). *Alaska Airports and Aviation – 2021 Annual Report*. Anchorage, AK, USA.

58 Tang R. Y. (2017). *Airport Privatization: Issues and Options for Congress*. Congressional Research Service.

59 De Neufville, R. (1999). Airport privatization: Issues for the United States. *Transportation Research Record*, (1662), 24–31. https://doi.org/10.3141/1662-03

60 Loi du n° 2005-357 du 20 avril 2005 relative aux aéroports. [Law No. 2005-357 of April 20, 2005 regarding airports]. NOR: EQUX0400177L. Version consolidée au 20 décembre 2019. [Consolidated version as of December 20, 2019] https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000786314.

61 Surplus Property Act of 1944, 50A U.S.C. § 1611 *et seq.* (1944).

62 Oxera for ACI Europe. (2017). *The continuing development of airport competition in Europe.*

63 Reuters. (2018). *Brazil's Viracopos airport operator files for bankruptcy protection.* https://www.reuters.com/article/idUSKBN1I810B/

64 Xu, F., Hanaoka, S., & Onishi, M. (2019). Multi-airport privatization in a Japanese region with trip-chain formation. *Journal of Air Transport Management*, 80. https://doi.org/10.1016/j.jairtraman.2019.101690

65 Tani, R., et al. (2022). Analysis of the effect of bundled airport privatization on an airline network. *Transport Policy*, 124, 203–211. https://doi.org/10.1016/j.tranpol.2021.04.021

66 BNDES. (2016). *Airport infrastructure auctions.* Rio de Janeiro. RJ, Brazi,. https://www.bndes.gov.br/ SiteBNDES/bndes/bndes_en/Institucional/Press/Noticias/2016/airport_infrastructure_auctions.html.

67 EIB. (2008). *EIB financing of airport projects.* Kirchberg, Luxembourg. https://www.eib.org/en/press/news/eib-financing-of-airport-projects.htm.

68 Kaplan Kirsch & Rockwell. (2019). *Paine Field Commercial Service and Passenger Terminal.* https://www.kaplankirsch.com/projects/paine-field-commercial-service-and-passenger-terminal/.

69 Huffpost. (2012). *Ciudad Real International Airport Sits Abandoned In Central Spain.* https://www.huffpost.com/entry/ciudad-real-international_n_1667526.

70 Ferrandis, J. (2015). *Brussels to investigate subsidies at Castellón's "airport with no planes".* El País. https://english.elpais.com/elpais/2015/09/10/inenglish/1441874227_797420.html.

71 ACI World/IATA. (2020). The NEXTT Vision in a post-COVID-19 World. https://www.iata.org/contentassets/bf24e4583c4f4e6398e3ec0b9f6335ed/nextt-vision-post-covid-19-world-1.pdf

72 Whitmore, G. (April 5, 2019). *Should You Join An Airport Rewards Program?* Forbes. https://www.forbes.com/sites/geoffwhitmore/2019/04/05/should-you-join-an-airport-rewards-program/

73 Future Airport (December 21, 2017). Beacon technology for airport mobile apps. https://www.futureairport.com/features/featurebeacon-technology-for-airport-mobile-apps-6199220/

74 Le Bris, G. et al. (2024). Conceptualizing Intermodal Facilities. *Enhancing Airport Access with Emerging Mobility.* Transportation Research Board. National Academies. Washington, D.C, USA.

75 Jung, J. et al. (2021). Overview of NASA's Extensible Traffic Management (xTM) Research. https://ntrs.nasa.gov/api/citations/20210025112/downloads/20210025112_Jung_SciTech2022.pdf?attachment=true

76 ICAO. (2018). Manual on Collaborative ATFM. Doc 9971. 3rd edition.

77 ICAO. (2016). 2016-2030 Global Air Navigation Plan. Doc 9750-AN/963. 5th edition. https://www.icao.int/airnavigation/documents/ganp-2016-mobile.pdf

78 San Diego International Airport/Detecon Innovation Institute. (2018). *San Diego International Airport Innovation Lab.* San Diego, CA, USA.

79 Markel, A. and Sanghvi, A. (2022). Addressing Electric Aviation Infrastructure Cybersecurity Implementation. National Renewable Energy Laboratory. NREL/TP-5R00-82856. https://www.nrel.gov/docs/fy23osti/82856.pdf

80 del Pozo, B. (2023). Complexity, Lethality, and the Perverse Imagination: Modelling Nonstate Actors' Means of Attack. *Studies in Conflict and Terrorism*, 46(11), 2351–2362. https://doi.org/10.1080/1057610X.2021.1906483

81 Duchesneau, J., & Langlois, M. (2017). Airport attacks: The critical role airports can play in combatting terrorism. *Journal of Airport Management*, Vol II(No 4), 342–354.

82 McCrie, R., & Haas, D. (2018). Why Airline Passenger Screening Will Be With Us Forever: Past, Present, and Prospects for Air Travel Safety. *Journal of Applied Security Research*, 13(2), 149–159.

83 Parent, T. et al. (2018). PARAS 0013: Managing Congestion in Public Areas to Mitigate Security Vulnerabilities. National Safe Skies Alliance. https://www.sskies.org/images/uploads/subpage/PARAS_0013.MinimizingCongestion.FinalReport-Final.pdf

84 Farr BD, O. et al. (2021). Expert Perspectives on the Performance of Explosive Detection Canines: Operational Requirements. *Animals*,11(7):1976. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8300389/

85 Gonzalez, R. (December 11, 2017). The Las Vegas Resort Using Microwaves to Keep Guns Out of its Casino. *Wired*. https://www.wired.com/story/the-las-vegas-resort-using-microwaves-to-keep-guns-out-of-its-casino/

86 ASTM International. (2018). *ASTM F2656 / F2656M-18a. Standard Test Method for Crash Testing of Vehicle Security Barriers*. West Conshohocken, PA, USA.

87 Broward County Aviation Department. (2017). *Fort Lauderdale-Hollywood International Airport Active Shooter Incident and Post-Event Response – January 6, 2017: After-Action Report*. Broward County. https://www.sskies.org/images/uploads/subpage/Ft.-Lauderdale-Hollywood-International-Airport-AAR_.pdf

88 Williams, J. (October 2, 2017). White American men are a bigger domestic terrorist threat than Muslim foreigners. *Vox*. https://www.vox.com/world/2017/10/2/16396612/las-vegas-mass-shooting-terrorism-islam

89 Williams, H, J. et al. (2022). *A Dangerous Web: Mapping Racially and Ethnically Motivated Violent Extremism*. RAND Corporation. https://www.rand.org/pubs/research_briefs/RBA1841-1.html

90 Jones, S. G. et al. (2020). *The War Comes Home: The Evolution of Domestic Terrorism in the United States*. Center for Strategic & International Studies. https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/201021_Jones_War_Comes_Home_v2.pdf

91 U.S. Government Accountability Office. (2023). *Domestic Terrorism: Further Actions Needed to Strengthen FBI and DHS Collaboration to Counter Threats*. Report GAO-23-104720.

92 Federal Aviation Administration. (n.d.). *Dangerous Behavior Doesn't Fly: Unruly Passenger Statistics*. https://www.faa.gov/unruly

93 Reverdosa, M. and Ehlinger, M. (December 26, 2022). Police arrest man suspected of planting explosives in Brazil's capital ahead of presidential inauguration. *CNN*. https://www.cnn.com/2022/12/25/americas/brazil-presidential-inauguration-explosives-arrest/index.html

94 Bergengruen, V. (January 9, 2023). 'Is There Something More Sinister Going On?' Authorities Fear Extremists Are Targeting U.S. Power Grid. *Time*. https://time.com/6244977/us-power-grid-attacks-extremism/

95 Carnegie Science. (August 12, 2016). *"Chemtrails" not real, say leading atmospheric science experts*. https://carnegiescience.edu/news/%E2%80%9C-chemtrails%E2%80%9D-not-real-say-leading-atmospheric-science-experts

96 Spadaro, P. A. (2020). Climate Change, Environmental Terrorism, Eco-Terrorism and Emerging Threats. *Journal of Strategic Security*, 13(4). https://doi.org/10.5038/1944-0472.13.4.1863

97 Chermak, S. M. (2013). *An Overview of Bombing and Arson Attacks by Environmental and Animal Rights Extremists in the United States, 1995-2010*. Final Report to the Resilient Systems Division. Science and Technology Directorate, U.S. Department of Homeland Security.

98 Pappas, S. (June 16, 2016). The Science of Mass Shooters: What Drives a Person to Kill? *Scientific American*. https://www.scientificamerican.com/article/the-science-of-mass-shooters-what-drives-a-person-to-kill/

99 Kaiser, S. A. (2010). Aviation Security: Technical and Regulatory Measures against MANPADS. *Air and Space Law*, 35(Issue 1), 45–58. https://doi.org/10.54648/aila2010004

100 Zeigler, S. et al. (2019). *Acquisition and Use of MANPADS Against Commercial Aviation: Risks, Proliferation, Mitigation, and Cost of an Attack*. Santa Monica, CA: RAND Corporation. https://www.rand.org/pubs/research_reports/RR4304.html

101 Rose, A. et al. (2016). *The Role of Behavioral Responses in the Total Economic Consequences of Terrorist Attacks on U.S. Air Travel Targets*. Risk Analysis. Volume 31. Issue 7. p.p. 1403-1418. https://doi.org/10.1111/risa.12727

102 Dutch Safety Board. (2015). *Crash of Malaysia Airlines flight MH17.*

103 Joint Investigation Team MH17. (2023). *Findings of the JIT MH17 investigation into the crew members of the Buk TELAR and those responsible in the chain of command.* Openbaar Ministerie.

104 ICAO. (August 8, 2022). *GNSS Interference. Agenda Item 31: Aviation Safety and Air Navigation Standardization.* Assembly – 41st Session: Technical Commission. Working Paper A41-WP/196.

105 EASA. (November 6, 2023). *Global Navigation Satellite System Outage and Alterations Leading to Navigation / Surveillance Degradation*. SIB No.: 2022-02R2.

106 U.S. Department of Transportation. (January 25, 2024). *Recognizing and Mitigating Global Positioning System (GPS) / Global Navigation Satellite System (GNSS) Disruptions.* SAFO 24002.

107 ICAO. (2023). *Risk Assessment Manual for Civil Aircraft Operations Over or Near Conflict Zones.* Doc 10084. 3rd Edition. Montréal, QC, Canada.

108 Le Bris, G. et al. (2023). *Building Resilience Toward Emerging Global Threats on Aviation.* AV090 Research Need Statements. National Academies. https://www.mytrb.org/RNS/Details/1963

109 Jenkins, B. M. (2016). Nuclear Terrorism, the Last 40 Years: What Has and Has Not Happened. Remarks before the NPEC Fellowship Retreat—February 27, 2016. In *Working Paper 1602: The Nuclear Terrorism Threat: How Real Is It? Two Views by Brian Michael Jenkins and John Lauder.* Nonproliferation Policy Education Center.

110 Unal, B. and Aghlani, S. (2016). *Use of Chemical, Biological, Radiological and Nuclear Weapons by Non-State Actors Emerging trends and risk factors.* Lloyd's Emerging Risk Report – Innovation Series. Chatham House.

111 Gerstein, D. M. et al. (2024). *Emerging Technology and Risk Analysis: Synthetic Pandemics.* Homeland Security RAND Corporation. https://www.rand.org/pubs/research_reports/RRA2882-1.html

112 Olivares, G. et al. (2017). Executive Summary – Structural Evaluation. *UAS Airborne Collision Severity Evaluation.* National Institute for Aviation Research/ Wichita State University.

113 EASA. (2023). Research Project EASA.2020.C04: *Vulnerability of manned aircraft to drone strikes.* Report D8.1 & D8.2.

114 U.S. Department of Homeland Security. (2020). *Protecting Against the Threat of Unmanned Aircraft Systems (UAS): An Interagency Security Committee Best Practice.* https://www.cisa.gov/sites/default/files/publications/Protecting%20Against%20the%20Threat%20of%20Unmanned%20Aircraft%20Systems%20November%202020_508c.pdf

115 Figueiredo, B. (2022). *The Use of Uncrewed Aerial Systems by Non-State Armed Groups Exploring Trends in Africa.* UNIDIR. https://unidir.org/wp-content/uploads/2024/01/UNIDIR_Use_of_Uncrewed_Aerial_Systems_by_Non_State_Armed_Groups_Africa.pdf

116 ICAO. (2023). Protection of Civil Aviation Infrastructure Against Unmanned Aircraft. https://www.icao.int/Security/SFP/Documents/UAS_InfraProtection%20-%20Abriged.EN.pdf

117 IBM. (2024). X-Force Threat Intelligence Index.

118 Ukyab, K. (2021). *Are cyber attacks the next big thing: Improving cybersecurity at airports.* ACI World Insights. https://blog.aci.aero/are-cyber-attacks-the-next-big-thing-improving-cybersecurity-at-airports/

119 Strom, B. E. et al. (2020). *MITRE ATT&CK: Design and Philosophy.* Report MP180360R1. MITRE corporation. https://attack.mitre.org/docs/ATTACK_Design_and_Philosophy_March_2020.pdf

120 ICAO. (2019). Security and Facilitation Strategic Objective: Aviation Cybersecurity Strategy.

121 Le Bris, G. (2023). Aerial Innovation & Cybersecurity: Securing the Future Aviation Ecosystem. *Cybersecurity Week*. Agência Nacional de Aviação Civil.

122 Flight Safety Foundation. (2024). Statistics by Period. *Aviation Safety Network*. https://aviation-safety.net/statistics/period/stats.php?cat=H2

123 ICAO. (2017). *Global Aviation Security Plan*. Doc 10118. 1st edition. Montreal, QC, Canada.

124 U.S. Department of Homeland Security. (March 4, 2024). *Screening at Speed*. Transportation Security Administration. https://www.dhs.gov/science-and-technology/screening-at-speed

125 U.S. Department of Homeland Security. (March 6, 2024). *TSA and DHS S&T to prototype self-service screening system at Harry Reid International Airport*. Transportation Security Administration. https://www.tsa.gov/news/press/releases/2024/03/06/tsa-and-dhs-st-prototype-self-service-screening-system-harry-reid

126 Friedman, J. et al. (2023). PARAS 0049: *Creating and Maintaining a Strong Security Culture at Airports*. National Safe Skies Alliance. https://www.sskies.org/images/uploads/subpage/PARAS_0049.AirportSecurityCulture_.FinalReport_.pdf

127 Smith, J. F. et al. (2023). PARAS 0051: *Guidance for Airport Security Exercises*. National Safe Skies Alliance. https://www.sskies.org/images/uploads/subpage/PARAS_0051.AirportSecurityExercises_.Final_.pdf

128 Johnson, B. R. (2010). Property Crime at O'Hare International Airport: An Examination of the Routine Activities Approach. *Journal of Applied Security Research*, 5(1), pp. 42–63. https://www.tandfonline.com/doi/abs/10.1080/19361610903407814 4

129 U.S. Department of State. (2023). *2023 Trafficking in Persons Report*. Washington. D.C. USA.

130 ICAO. (2023). Manual on a Comprehensive Strategy for Combating Human Trafficking in the Aviation Sector. Doc 10171. 1st Edition. Montréal, QC, Canada.

131 Boeing. (2023). *Statistical Summary of Commercial jet Airplane Accidents. Worldwide Operations I 1959-2022.*

132 Craig, P. A. (2013). *The Killing Zone – How and Why Pilots Die*. 2nd Edition. McGraw-Hill. pp. 1-16.

133 DGAC/STAC. (2011). Déviation des aéronefs à l'atterrissage. Note d'information technique. https://www.stac.aviation-civile.gouv.fr/en/guides/aircraft-lateral-deviation-during-landing

134 DGAC/STAC. (2013). Séparations des voies de circulation pour aéronefs de code C. Note d'information technique. https://www.stac.aviation-civile.gouv.fr/en/guides/taxiway-separation-icao-code-c-aeroplanes

135 EASA. (2015). Explanatory Note to Decision 2015/001/R. Update of CS ADR-DSN.D.260 Taxiway minimum separation distance 'CS-ADR-DSN — Issue 2'. https://www.easa.europa.eu/sites/default/files/dfu/EN%20to%20ED%20Decision%202015-001-R_0.pdf

136 Hall, J. W. Jr. et al. (2011). ACRP Report 51: Risk Assessment Method to Support Modification of Airfield Separation Standards. National Academies.

137 ICAO. (April 19, 2017). Proposals for the Amendment of Annex 14, Volume I and PANS-Aerodromes (DOC 9981). State Letter Ref. AN 4/1.1.57-17/44.

138 ICAO. (2022). *Annex 14 to the Convention on International Civil Aviation, Volume I – Aerodrome Design and Operations*. 9th Edition. Montréal, QC, Canada.

139 FAA. (2012). *Advisory Circular 150/5220-22B, FAA/AAS-100: Engineered Materials Arresting Systems (EMAS) for Aircraft Overruns*. Washington, DC, USA.

140 National Academies. (n.d.). ACRP 04-28 [Active]. Developing Alternative Aircraft Arresting Systems. Accessing April 12, 2024. https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=5033

141 Mahoney, T. F. (2015). ACRP Problem Statement 17-04-16. Developing Arresting Systems for Small Aircraft at General Aviation Airports.

142 U.S. Department of Commerce – National Technical Information Service. (1952). *The Airport and its Neighbors, The Report of the President's Airport Commission*. Washington, DC, USA.

143 FAA. (2022). *Advisory Circular 150/5300-13B: Airport Design.* Section 3.13 – Runway Protection Zones. Washington, DC,USA.

144 FAA. (2022). *Advisory Circular 150/5190-4B: Airport Land Use Compatibility Planning.* Washington, DC, USA.

145 ICAO. (2018). *Safety Management Manual (SMM).* Doc 9859. 4th Edition.

146 Transportation Research Board. (n.d.) *Airport Cooperative Research Program.* http://www.trb.org/ACRP/ACRP.aspx.

147 DGAC/STAC. (2015). *Ground handling and flight safety: Best practices and awareness-raising.* https://www.stac.aviation-civile.gouv.fr/en/guides/ground-handling-and-flight-safety

148 EASA. (2024). Opinion No 01/2024 in accordance with Article 76(1) of Regulation (EU) 2018/1139. Ground handling requirements (RMT.0728).

149 ICAO. (2020). *Manual on the Development of Regional and National Aviation Safety Plans.* Doc 101310 1st Edition.

150 FAA. (n.d.). *Aviation Safety Information Analysis and Sharing (ASIAS) 3.0.* Performance Work Statement (PWS).

151 FAA. (2009). AC 150/5220-24: *Foreign Object Debris Detection Equipment.*

152 FAA. (n.d.). *FAA Foreign Object Debris Program.* https://www.faa.gov/airports/airport_safety/fod

153 DGAC/STAC. (2011). *Systèmes de détection des objets sur les pistes d'aérodrome.* Rapport d'étude. https://www.stac.aviation-civile.gouv.fr/en/guides/systems-automated-detection-objects-and-debris-runway

154 ICAO. (2022). "Autonomous runway incursion warning system". In *Annex 14 to the Convention on International Civil Aviation, Volume I – Aerodrome Design and Operations.* 9th Edition. Montréal, QC, Canada. pp. 9-16 to 9-17 & ATT A-31 to A-33.

155 FAA. (n.d.). *Runway Status Light (RWSL).* https://www.faa.gov/air_traffic/technology/rwsl/.

156 Dipierro, G. and Higginbotham, R. (March 16, 2022). Runway Incursion Reduction Program (RIRP) Overview. Federal Aviation Administration.

157 EUROCONTROL et al. (2023). Global Action Plan for the Prevention of Runway Incursions. *Volume I — Recommendations.*

158 Jones, D. R. et al. (2001). *RUNWAY INCURSION PREVENTION SYSTEM – DEMONSTRATION AND TESTING AT THE DALLAS/FORT WORTH INTERNATIONAL AIRPORT.* Presented at the 20th Digital Avionics Systems Conference, Daytona Beach, Florida, October 14-18, 2001.

159 EASA. (2010). *Runway friction characteristics measurement and aircraft braking (RuFAB).* https://www.easa.europa.eu/document-library/research-reports/easa20084.

160 Jacob, A. et. al. (2009). *The Runway Overrun Prevention System.* Safety First #08. Airbus.

161 Jenkins, M. & Aaron R. F. Jr. (2012). *Reducing Runway Landing Overruns.* Aero QTR 03.12. Boeing.

162 ICAO. (2021). *The New Global Reporting Format for Runway Surface Conditions.* https://www.icao.int/safety/Pages/GRF.aspx.

163 ICAO. (2013). Chapter 4. Coefficient of Friction and Friction Measuring Devices. In *Industry best Practices Manual for Timely and Accurate Reporting of Runway Surface Conditions by ATS/AIS to Flight Crew.* Draft Version 4.0. Regional Aviation Safety Group (RASG).

164 Ellis, K. K. et al. (2022). The In-time Aviation Safety Management System Concept for Part 135 Operators. IEEE DASC 2022.

165 ICAO. (2019). *2020-2022 Global Aviation Safety Plan.* Doc 10004.

166 ICAO. (2023). *Safety Report.*

167 ICAO. (2018). Section 8.2. State Safety Programme (SSP). In *Safety Management Manual (SMM)*. Doc 9859. 4th Edition.

168 Nzuzi, A. (2017). *A Balanced Approach to Safety Oversight and Management in States with a Low Level of Compliance to ICAO SARPs.* ENAC Alumni Magazine. No. 20. pp. 44-46.

169 Mallela, J. et al. (2023). ACRP Research Report 243: Urban Air Mobility: An Airport Perspective. Transportation Research Board, Washington, DC: https://nap.nationalacademies.org/catalog/26899/urban-air-mobility-an-airport-perspective

170 Airbus Helicopters. (2013). *Eurocopter's X3 hybrid helicopter makes aviation history in achieving a speed milestone of 255 knots during level flight*. https://www.airbushelicopters.com/website/en/press/Eurocopter%27s-X3-hybrid-helicopter-makes-aviation-history-in-achieving-a-speed-milestone-of-255-knots-during-level-flight_1159.html.

171 Airbus. (April 25, 2024). Airbus Helicopters' Racer is off to a flying start. https://www.airbus.com/en/newsroom/press-releases/2024-04-airbus-helicopters-racer-is-off-to-a-flying-start

172 Lockheed Martin. (n.d.). *Raider X. Expanding the Envelope for Future Vertical Lift*. https://www.lockheedmartin.com/en-us/products/s-97-raider-helicopter.html.

173 Le Bris, G. et al. (2022). Preparing Your Airport for Electric Aircraft and Hydrogen Technologies. Transportation Research Board, Washington, DC: https://nap.nationalacademies.org/catalog/26512/preparing-your-airport-for-electric-aircraft-and-hydrogen-technologies

174 Harbour Air. (2019). *Harbour Air and magniX Announce Successful Flight of World's First Commercial Electric Airplane*. https://www.harbourair.com/harbour-air-and-magnix-announce-successful-flight-of-worlds-first-commercial-electric-airplane/.

175 Seyam, S. et al. (2022). Economic and environmental impact assessments of hybridized aircraft engines with hydrogen and other fuels. *International Journal of Hydrogen Energy*, *47*(22), pp. 11669–11685. https://doi.org/10.1016/j.ijhydene.2022.01.171

176 Prashanth, P. et al. (2021). Post-combustion emissions control in aero-gas turbine engines. *Energy & Environmental Science, 14*, pp. 916–930. https://pubs.rsc.org/en/content/articlepdf/2021/ee/d0ee02362k

177 Gimenez, F. R. et al. (2023). Assessment of different more-electric and hybrid-electric configurations for long-range multi-engine aircraft. *Journal of Cleaner Production*, volume 392. https://doi.org/10.1016/j.jclepro.2023.136171

178 Airbus (n.d.). Hybrid and electric flight: Laying the groundwork for decarbonizing aviation. https://www.airbus.com/en/innovation/low-carbon-aviation/hybrid-and-electric-flight

179 Baldanza, B. (July 6, 2023). Commercial 50 And Fewer Seat Aircraft Are Economically Dead. https://www.forbes.com/sites/benbaldanza/2023/07/06/commercial-50-and-fewer-seat-aircraft-are-economically-dead/?sh=9487c87079ee

180 Silk, R. (August 10, 2021). Airlines retiring their smallest planes, raising concerns for small markets. Travel Weekly. https://www.travelweekly.com/Travel-News/Airline-News/Airlines-retiring-smallest-planes

181 William, J. D. and Rathsam, J. (2019). How loud is X-59's shaped sonic boom? 177th Meeting of the Acoustical Society of America. *Proceedings of Meetings on Acoustics, 36*(1). https://doi.org/10.1121/2.0001265

182 Kharina, A. et al. (2018). *Environmental performance of emerging supersonic transport aircraft.* ICCT Working Paper 2018-12. https://theicct.org/wp-content/uploads/2021/06/Environmental_Supersonic_Aircraft_20180717.pdf.

183 Eastham, S. D. et al. (2022). *Impacts of a near-future supersonic aircraft fleet on atmosphericcomposition and climate.* Environmental Science: Atmospheres. https://dspace.mit.edu/bitstream/handle/1721.1/145279/d1ea00081k.pdf

184 ACIACI World. (2019). *ACI's Views on the Reintroduction of Supersonic Aircraft and the Development of Appropriate SARPs.* ICAO Working Paper A40-WP/225 EX/85.

185 Sänger, E. and Bredt, J. (1944). *A Rocket Drive for Long Range Bombers* [Tiber elnen Raketenantrleb for Fernboober]. Deutsche Luftfahrtforschung. UM 3538. Translation CGD-32 by Hamermesh, M.

186 Bowcutt, K. G. (2020) Flying at the Edge of Space and Beyond: The Opportunities and Challenges of Hypersonic Flight. The Bridge, Summer 2020, Aeronautics. National Academy of Engineering.

187 Piesing, M. (January 2, 2024). Are We in an Airship Renaissance? Smithsonian Magazine. https://www.smithsonianmag.com/blogs/air-space-museum/2024/01/02/airship-renaissance/

188 ANAC. (December 23, 2022). ANAC aprova dirigível fabricado no Brasil. https://www.gov.br/anac/pt-br/noticias/2022/anac-aprova-dirigivel-fabricado-no-brasil

189 Richardson, J. (February 6, 2024). Seaplane renaissance. Royal Aeronautical Society. https://www.aerosociety.com/news/seaplane-renaissance/

190 Hemmerdinger, J. (July 18, 2023). But is it an aircraft? FAA undecided on critical question as Regent seeks 'seaglider' guidance. https://www.flightglobal.com/airframers/but-is-it-an-aircraft-faa-undecided-on-critical-question-as-regent-seeks-seaglider-guidance/154119.article

191 REGENT. (August 30, 2022). REGENT Receives Classification Approval in Principle for a Wing-in-Ground Vessel from Bureau Veritas. https://www.regentcraft.com/news/regent-receives-approval-in-principle-for-a-wing-in-ground-vessel-classification-from-bureau-veritas

192 IIWG. (2007). Commercial Aircraft Design Characteristics – Trends and Growth Projections. 5th Edition, Revision 1. https://www.airbus.com/sites/g/files/jlcbta136/files/2021-11/Airbus-Commercial-Aircraft-CADC.pdf

193 Le Bris, G. (2014). *Accommodating the next generation of airliners*. International Airport Review.

194 ICAO. (2004). *Operation of New Larger Aeroplanes at Existing Aerodromes*. Circular 305 AN/177.

195 ACI World. (2002). *Common Agreement Document – Airbus A380 Airport Compatibility Group (AACG)*. Version 2.1.

196 ACI World. (2008). *Common Agreement Document – Boeing 747-8 Airport Compatibility Group (BACG).*

197 ACI World. (2018). *Common Agreement Document – Boeing 777-8/-9 Airport Compatibility Group* (BACG2).

198 Civil Aviation Safety Authority. (2014). *Minimum Runway Width – for aeroplanes engaged in RPT and Charter operations with a maximum take-off weight greater than 5700 kg*. CAAP 235A-1(0).

199 Root, R. (n.d.). *Guidelines for Narrow Runway Operations*. Boeing.

200 Ayres Jr. M. et al. (2011). *ACRP Report 50: Improved Models for Risk Assessment of Runway Safety Areas*. Transportation Research Board. National Academies. Washington, DC, USA.

201 DFS et al. (2006). *Assessment of ILS protection areas impact on large aircraft operations*. Version 1.3.

202 Le Bris, G. et al. (2024). Additional Services to Passengers. *Enhancing Airport Access with Emerging Mobility*. Transportation Research Board. National Academies. Washington, DC, USA.

203 EUROCONTROL. (2024). *Sustainable Taxi Operations: Concept of Operations & Industry Guidance*. Edition 1.0.

204 NASA. (n.d.). *About Advanced Air Vehicles Program (AAVP).*

205 Clean Sky. (2021). *Clean Sky at a Glance*.

206 Flottau, J. and Osborne, T. (June 14, 2023). Airbus CEO Guillaume Faury Reveals Plans for New-Generation Narrowbody. *Aviation Week Network*. https://aviationweek.com/shownews/paris-air-show/airbus-ceo-guillaume-faury-reveals-plans-new-generation-narrowbody

207 Ostrower, Jon. and Guisbond, W. (February 6, 2024). Airbus turns up the volume on planning for a clean-sheet single aisle. *The Air Current*. https://theaircurrent.com/aircraft-development/airbus-ngsa-eaction-rendering-new-airplane/

208 Airbus. (n.d.). ZEROe: Towards the world's first hydrogen-powered commercial aircraft. https://www.airbus.com/en/innovation/low-carbon-aviation/hydrogen/zeroe

209 Flottau, J. (June 1, 2023). Boeing To Focus On Truss-Braced Wing, Autonomy For Next Aircraft, Calhoun Says. *Aviation Week Network*. https://aviationweek.com/air-transport/aircraft-propulsion/boeing-focus-truss-braced-wing-autonomy-next-aircraft-calhoun

210 Strickland, A. (January 19, 2023). New aircraft design from NASA and Boeing could benefit passengers in the 2030s. *CNN Travel*. https://www.cnn.com/travel/article/nasa-sustainable-flight-demonstrator-climate-scn/index.html

211 Hemmerdinger, J. (December 5, 2022). Embraer shifts 'Energia' focus to new hybrid- and hydrogen-powered concepts. *FlightGlobal.com*. https://www.flightglobal.com/airframers/embraer-shifts-energia-focus-to-new-hybrid-and-hydrogen-powered-concepts/151225.article

212 Tangel, A. and Katz, B. (May 1, 2024). Brazil's Embraer Plots a New 737-Sized Jet to Rival Boeing. *The Wall Street Journal*. https://www.wsj.com/business/airlines/boeing-partner-embraer-aircraft-manufacturing-edf3758a

213 Le Bris, G. (2024). Accueillir la prochaine génération d'aéronefs : les enjeux de compatibilité aéroportuaire à l'horizon 2035. *Aéroport Le Mag*.

214 Hofacker, C. (March 2023). The bridge to net-zero. *Aerospace America*. https://aerospaceamerica.aiaa.org/departments/the-bridge-to-net-zero/

215 AnonymousFLIGHT. (November 28, 1952). Hurel Dubois Transports. Progress with the HD-31 and 32: The HD-45 Jet Project. *FLIGHT*.

216 O'Shea, C. A. (June 12, 2023). Next Generation Experimental Aircraft Becomes NASA's Newest X-Plane. *NASA*. https://www.nasa.gov/news-release/next-generation-experimental-aircraft-becomes-nasas-newest-x-plane/

217 Bradley, M. et al. (2015). *Subsonic Ultra Green Aircraft Research: Phase II – Volume I – Truss Braced Wing Design Exploration*. NASA/CR–2015-218704/Volume I. https://ntrs.nasa.gov/api/citations/20150017036/downloads/20150017036.pdf

218 Welsh, J. (August 17, 2023). JetZero Receives $235M Defense Department Award to Develop Blended-Wing Aircraft. *Flying*. https://www.flyingmag.com/jetzero-receives-235m-defense-department-award-to-develop-blended-wing-aircraft/

219 JetZero. (n.d.). Why JetZero. https://www.jetzero.aero/why-jetzero

220 D'Urso, S. (August 17, 2023). U.S. Air Force Announces Development Of Blended Wing Body Aircraft Demonstrator. *The Aviationist*. https://theaviationist.com/2023/08/17/usaf-blended-wing-body-aircraft/

221 Hultgren, L. S. (2011). *Core Noise: Implications of Emerging N+3 Designs & Acoustic Technology Needs – Subsonic Fixed Wing project*. Acoustics Technical Working Group Cleveland, OH, April 21-22, 2011.

222 Baudis, P. et al. (2023). *Aircraft and Engine Innovations & Designs to Decarbonize Commercial Aviation*. https://www.alumni.enac.fr/fr/news/aircraft-and-engine-innovations-designs-to-decarbonize-commercial-aviation-928

223 Jansen, R. et al. (2017). *Overview of NASA Electrified Aircraft Propulsion (EAP) Research for Large Subsonic Transports*. AIAA 2017-4701. https://doi.org/10.2514/6.2017-4701

224 ATR. (May 18, 2022). *ATR paves way for next generation of its best-selling aircraft (press release)*.

225 Rane, J., et al. (2023). *Overview of Potential Hazards in Electric Aircraft Charging Infrastructure*. National Renewable Energy Laboratory. NREL/TP-5R00-83429. https://www.nrel.gov/docs/fy24osti/83429.pdf

226 Newman, D. I. (2023). Coming to Terms: Taxonomy of VTOL Aircraft Configuration Types — Part 2. *Vertiflite*, Jan/Feb 2023. https://evtol.news/news/

taxonomy-of-vtol-aircraft-configuration-types-part-2

227 Snyder, C. A. (2020). *More / All Electric Vertical Take-Off and Landing (VTOL) Vehicle Sensitivities to Propulsion and Power Performance.* Vertical Flight Society, Forum 76.

228 Uber Elevate. (2016). *Fast-Forwarding to a Future of On-Demand Urban Air Transportation.*

229 Uber. (2020). *UberAir Vehicle Requirements and Missions.*

230 FAA. (2023). *Advanced Air Mobility (AAM) Implementation Plan: Near-term (Innovate28) Focus with an Eye on the Future of AAM.* Version 1.0.

231 EASA. (2024). What is UAM? https://www.easa.europa.eu/en/what-is-uam

232 ANAC. (2023). *Advanced Air Mobility: Panorama e perspectivas.* Superintendênciq de Aeronavigabilidade. https://www.gov.br/anac/pt-br/centrais-de-conteudo/publicacoes/publicacoes-arquivos/aam-panorama-2023.pdf

233 MLIT. (March 18, 2022). *Advanced Air Mobility Roadmap. Public-Private Committee for Advanced Air Mobility.* https://www.meti.go.jp/policy/mono_info_service/mono/robot/pdf/2022_aam_roadmap_en.pdf

234 Goodrich, K. H. and Theodore, C. R. (2021). *Description of the NASA Urban Air Mobility (UAM) Maturity Level (UML) Scale.* Presented at AIAA SciTech.

235 EASA. (2022). Explanatory Note to Decisions 2022/022/R, 2022/023/R & 2022/024/R. *Development of and amendments to the acceptable means of compliance and guidance material to support the implementation of the U-space Regulation.*

236 SESAR Joint Undertaking. (2022). *Demonstrating the everyday benefits of U-space. Initial results from SESAR demonstrations (2020-2022).* https://sesar.eu/sites/default/files/documents/reports/Uspace_May2022__FINAL.pdf

237 FAA. (2023). *Urban Air Mobility (UAM) Concept of Operations v2.0.* https://www.faa.gov/sites/faa.gov/files/Urban%20Air%20Mobility%20%28UAM%29%20Concept%20of%20Operations%202.0_1.pdf

238 FAA. (2022). *UTM Concept of Operations Version 2.0 (UTM ConOps v2.0).* https://www.faa.gov/researchdevelopment/trafficmanagement/utm-concept-operations-version-20-utm-conops-v20

239 NASA. (n.d.). *Urban Air Mobility (UAM) Vision Concept of Operations (ConOps) UAM Maturity Level (UML) – 4: Overview.*

240 FAA. (2019). *Remote Identification of Uncrewed Aircraft Systems.* FAA Docket No. FAA-2019-1100 Notice No. 20-01. https://www.federal-register.gov/documents/2019/12/31/2019-28100/remote-identification-of-unmanned-aircraft-systems

241 EASA. (2019). *EASA publishes Opinion "Standard scenarios for UAS operations in the 'specific' category.* https://www.easa.europa.eu/newsroom-and-events/news/easa-publishes-opinion-%E2%80%9Cstandard-scenarios-uas-operations-%E2%80%98specific%E2%80%99.

242 ACI Europe. (2020). *Drones in the Airport Environment: Concept of Operations & Industry Guidance.*

243 EmbraerX/Atech. (2019). *Flight Plan 2030 – an Air Traffic Management Concept for Urban Air Mobility.*

244 Cluzeau J. M. et al. (2024). *Concepts of Design Assurance for Neural Networks (CoDANN) II.* Public Report Extract. Version 1.1. EASA AI Task Force.

245 Solanki, B. et al. (2023). *Federal Aviation Administration Vertiport Electrical Infrastructure Study.* National Renewable Energy Laboratory. NREL/TP-5R00-86245. https://www.nrel.gov/docs/fy24osti/86245.pdf

246 Le Bris, G. and Nguyen, L.-G. (2023). *An Airport & Vertiport/Aircraft Compatibility Approach of Electric Vertical Takeoff & Landing Aircraft Design.* Vertical Flight Society, Forum 79. https://doi.org/10.4050/F-0079-2023-18060

247 Le Bris, G. and Nguyen, L.-G. (2022). *Safety Considerations on the Operation of Electric Vertical and Takeoff Landing (VTOL) Aircraft at Airports and Vertiports.* Vertical Flight Society, Forum 78. https://doi.org/10.4050/F-0078-2022-17610

248 Khan, K. et al. (2024). *Shaping the Future of Advanced Air Mobility Safety*. RaeS President's 2024 Briefing Paper. Royal Aeronautical Society. https://www.aerosociety.com/media/23584/shaping-the-future-of-aam-safety-presidents-paper-2024.pdf

249 Le Bris, G. and Nguyen, L.-G. (2024). *TRB Webinar: Planning for the Emergence of Urban Air Mobility at Aviation Facilities*. National Academies. https://www.nationalacademies.org/event/848_02-2024_trb-webinar-planning-for-the-emergence-of-urban-air-mobility-at-aviation-facilities

250 Ozoroski, L, (2021). NASA Supersonic Research Strategy. https://ntrs.nasa.gov/api/citations/20210000675/downloads/CST-overview-vector-prime.pdf

251 Turner, J. (January 27, 2020). Sonic boom: do airports need to prepare for the supersonic revolution? *Airport Technology*. https://www.airport-technology.com/features/supersonic-passenger-aircraft/

252 FAA. (n.d.) *Spaceport License*. https://www.faa.gov/space/licenses/spaceport_license.

253 FAA. (2000). *U.S. 14 CFR Part 420 – License to Operate a Launch Site*. 51 U.S.C. 50901-50923. Docket No. FAA-1999-5833. 65 FR 62861. https://www.ecfr.gov/current/title-14/chapter-III/subchapter-C/part-420.

254 FAA. (2000). *U.S. 14 CFR Part 433 – License to Operate a Reentry Site*. 51 U.S.C. 50901-50923. Docket No. FAA-1999-5535. 65 FR 56665. https://www.ecfr.gov/current/title-14/chapter-III/subchapter-C/part-433.

255 Frodge, R. and Murray, D. (2022). Space Data Integration. *Journal of Space Safety Engineering, 9*(2), pp. 182–188. https://doi.org/10.1016/j.jsse.2022.02.015

256 Tinoco, J. K. et al. (2021). Sharing airspace: Simulation of commercial space horizontal launch impacts on airlines and finding solutions . *Journal of Space Safety Engineering, 8*(1), pp. 35–46. https://doi.org/10.1016/j.jsse.2021.02.001

257 Kaul, S. (2019). Integrating Air and Near Space Traffic Management for aviation and near space. *Journal of Space Safety Engineering, 6*(2), pp. 150–155. https://doi.org/10.1016/j.jsse.2019.06.004

258 Stilwell, R. et al. (2023). *High Altitude Platform Station Market Potential Enabled by Upper Class E Traffic Management*. AIAA Aviation 2023 Forum. https://doi.org/10.2514/6.2023-3960

259 HAPS Alliance. (2022). *HAPS Operation Using Attended Autonomous Fleet Systems: Collaborative Traffic Management for the Stratosphere*.

260 U.S. Government Accountability Office. (2023). *Air Traffic Control Modernization: Program Management Improvements Could Help FAA Address NextGen Delays and Challenges*. GAO-24-105254.

261 CANSO. (2024). ANSP Considerations for Managing Space Operations. https://canso.fra1.digitaloceanspaces.com/uploads/2024/02/ANSP-Considerations-for-Managing-Space-Operations.pdf

262 International Air Transportation Association (2022). *Net zero 2050: sustainable aviation fuels*. https://www.iata.org/en/iata-repository/pressroom/fact-sheets/fact-sheet---alternative-fuels/

263 International Civil Aviation Organization (2018). *Sustainable Aviation Fuels Guide*. https://www.icao.int/environmental-protection/knowledge-sharing/Docs/Sustainable%20Aviation%20Fuels%20Guide_vf.pdf

264 Air Transport Action Group (2017). *Beginner's Guide to Sustainable Aviation Fuel*. https://aviationbenefits.org/media/166152/beginners-guide-to-saf_web.pdf

265 U.S. Government Accountability Office (2023). *Sustainable Aviation Fuel: Agencies Should Track Progress Toward Ambitious Federal Goals*. https://www.gao.gov/products/gao-23-105300

266 Bhatt, A. H. et al. (2023). Evaluation of performance variables to accelerate the deployment of sustainable aviation fuels at a regional scale. *Energy Conversion and Management, 275*. https://doi.org/10.1016/j.enconman.2022.116441

267 Watson, M. J. et al. (2024). Sustainable aviation fuel technologies, costs, emissions, policies, and markets: A critical review. *Journal of Cleaner Production, 449*. https://doi.org/10.1016/j.jclepro.2024.141472

268 Sharma, B.P. et al. (2021). Economic Analysis of Developing a Sustainable Aviation Fuel Supply Chain Incorporating with Carbon Credits: A Case Study of the Memphis International Airport. *Frontiers in Energy Research, 9*. https://doi.org/10.3389/fenrg.2021.775389

269 Embraer. (n.d.). Future Aircraft Concepts. *Embraer*. https://embraercommercialaviationsustainability.com/concepts/

270 Mukhopadhaya, J. and Rutherford Dan (2022). Performance Analysis of Evolutionary Hydrogen-Powered Aircraft. International Council on Clean Transportation. https://theicct.org/publication/aviation-global-evo-hydrogen-aircraft-jan22/

271 Hoelzen J. et al. (2022). Hydrogen-powered aviation and its reliance on green hydrogen infrastructure – Review and research gaps. *International Journal of Hydrogen Energy, 47*(5), pp. 3108-3130.

272 Manigandan, S. et al. (2023). Role of hydrogen on aviation sector: A review on hydrogen storage, fuel flexibility, flame stability, and emissions reduction on gas turbines engines. *Fuel, 352*(129064). https://doi.org/10.1016/j.fuel.2023.129064

273 Blanco, H. et al. (2018). Potential for hydrogen and Power-to-Liquid in a low-carbon EU energy system using cost optimization. *Applied Energy, 232*, pp. 617–639. https://doi.org/10.1016/j.apenergy.2018.09.216

274 Rojas-Michaga, M. F. et al. (2023). Sustainable aviation fuel (SAF) production through power-to-liquid (PtL): A combined techno-economic and life cycle assessment. *Energy Conversion and Management, 292*(117427). https://doi.org/10.1016/j.enconman.2023.117427

275 International Air Transportation Association (2019). *FACT SHEET 7: Liquid hydrogen as a potential low carbon fuel for aviation*. https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/fact_sheet7-hydrogen-fact-sheet_072020.pdf

276 Le Bris, G. (November 2023). *Integrating Hydrogen Technologies at Airports & Vertiports*. HYSKY Monthly, HySky Society. https://www.youtube.com/watch?v=9oUOyU8saDY

277 Greenwood E., et al. (2022). Challenges and opportunities for low noise electric aircraft. *International Journal of Aeroacoustics, 21* (5-7):315-381. https://doi.org/10.1177/1475472X221107377

278 Joby Aviation. (May 10, 2022). *Joby Confirms Revolutionary Low Noise Footprint Following NASA Testing*. https://www.jobyaviation.com/news/joby-revolutionary-low-noise-footprint-nasa-testing/

279 Pascioni, K. A. et al. (2022). *Acoustic Flight Test of the Joby Aviation Advanced Air Mobility Prototype Vehicle*. https://ntrs.nasa.gov/api/citations/20220006729/downloads/Aeroacoustics2022_Pascioni_STRIVES5.pdf

280 Wendt-Lucas, N. (2023). *Charging Infrastructure. Implementing Electric Aviation: Critical Factors and Relevant Policy Instruments*. Nordregio working paper 2023:3. https://pub.nordregio.org/wp-2023-3-implementing-electric-aviation/

281 Le Bris, G. et al. (2023). TRB Webinar: Electrification and Hydrogen Technologies in Airports. https://www.nationalacademies.org/event/05-25-2023/trb-webinar-electrification-and-hydrogen-technologies-in-airports

282 Parsons, W. E., and Wilfert M. E. (1981). The *Varied Aspects of Aircraft/Airport Compatibility and Its Achievement*. Aircraft and Airport Compatibility Workshop, TRB Committee A3A16. Williamsburg, VA, October 26-28, 1981.

283 Welch, T. F., Mishra, S., & Wang, F. (2015). *Interrelationship between Airport Enplanements and Accessibility: Case of Three Airports in Metropolitan Washington, D.C., Region*. Transportation Research Record. 2501(1). https://doi.org/10.3141/2501-07

284 Clever, R., & Hansen, M. M. (2008). *Interaction of Air and High-Speed Rail in Japan*. Transportation Research Record. 2043(1). https://doi.org/10.3141/2043-01.

285 CDG Express. (n.d.). Les acteurs du projet CDG Express. *CDG Express*. https://cdgexpress.groupeadp.fr/.

286 Los Angeles World Airports. (2020). *Landside Access Modernization Program (LAMP). Mitigation Monitoring and Reporting Program 2019 Annual Progress Report.*

287 Anonymous. (February 6, 2014). Joe Biden Says LaGuardia Airport Like a "Third World Country". *NBC New York*. https://www.nbcnewyork.com/news/local/vice-president-joe-biden-laguardia-airport-third-world-country/2101554/

288 PANYNJ. (n.d.). *A Whole New LaGuardia*. https://www.anewlga.com/about-the-project/

289 Anonymous. (April 16, 2014). São Paulo–Guarulhos Airport: The gateway to Brazil. *International Airport Review*. https://www.internationalairportreview.com/article/16663/sao-paulo-guarulhos-airport-the-gateway-to-brazil/

290 Heathrow. (n.d.). Book Heathrow's complimentary personal shopping service. https://boutique.heathrow.com/en/personal-shopper

291 Taufik, N. and Hanafiah, M.H. (2019). Airport passengers' adoption behaviour towards self-check-in Kiosk Services: the roles of perceived ease of use, perceived usefulness and need for human interaction. *Heliyon, 5*(12). https://doi.org/10.1016/j.heliyon.2019.e02960

292 Castillo-Manzano, J. I. and López-Valpuesta, L. (2013). Check-in services and passenger behaviour: Self service technologies in airport systems. *Computers in Human Behavior, 29*(6), pp. 2431–2437. https://doi.org/10.1016/j.chb.2013.05.030

293 De Neufville, R. (1975). *Designing the Airport Terminal*. Workshop 5 Resource Paper. Conference on Airport Landside Capacity. Transportation Systems Center and Federal Aviation Administration. Tampa, Florida, USA.

294 Stewart, R. (2024). The Evolution of Airport Design. 1st Edition.

295 Boudreau, B. J., et al. (2016). *ACRP Report 157: Improving the Airport Customer Experience*. Transportation Research Board. National Academies. Washington, D.C. USA. pp. 14-16.

296 ACI-NA. (2020). *Members of Congress Announce Framework for Infrastructure Bill That Includes a PFC Increase*. https://airportscouncil.org/2020/02/03/members-of-congress-announce-framework-for-infrastructure-bill-that-includes-a-pfc-increase/.

297 Airlines for America. (2019). *Five More Reasons to Oppose an Increase to the Passenger Facility Charge*. https://www.airlines.org/news/five-more-reasons-to-oppose-an-increase-to-the-passenger-facility-charge/.

298 Air Asia. (2020). *How Airport Tax Increases Might Affect You*. https://newsroom.airasia.com/how-airport-tax-increases-might-affect-you.

299 MERCOSUL. (2008). *Acordo sobre documentos de viagem dos estados partes do MERCOSUL e estados associados*. MERCOSUL.CNC.DEC No. 18/08.

300 Daley, J. (July 22, 2016). *Common African Union Passport to Allow Free Movement Across the Continent. Smithsonian Magazine*.

301 UNWTO. (2014). *The Impact of Visa Facilitation in ASEAN Member States*.

302 Peterson, B. (May 27, 2016). Delta's "Innovation Lanes" Hope to Speed Up Airport Security. *Condé Nast Traveler*.

303 Air Transport Action Group (ATAG). (2005). *The economic & social benefits of air transport*. Geneva.

304 Federal Aviation Administration. (2024). *Air Traffic by the Numbers*. https://www.faa.gov/air_traffic/by_the_numbers.

305 Network Manager nominated by the European Commission. (2019). *Industry Monitor*. Issue No.205. EUROCONTROL.

306 EUROCONTROL. (2018). *Standard Inputs for EUROCONTROL Cost-Benefit Analyses*. Edition 8.0. Brussels. Belgium.

307 ICAO. (n.d.). *Post-COVID-19 forecasts scenarios*. https://www.icao.int/sustainability/Pages/Post-Covid-Forecasts-Scenarios.aspx.

308 ICAO. (2016). *China's Strategy for Modernizing Air Traffic Management, presented by the People's Republic of China*. Working Paper. 39th Assembly – Technical Commission.

309 Welman, S., et al. (2010). *Calculating Delay Propagation Multipliers for Cost-Benefit Analysis*. MITRE Product MP1000039. CAASD., The MITRE corporation.

310 Official Journal of the European Union. (2019). *Commission Implementing Regulation (EU) 2019/317 of 11 February 2019 laying down a performance and charging scheme in the single European sky and repealing Implementing Regulations (EU) No 390/2013 and (EU) No 391/2013*.

311 Civil Air Navigation Services Organization (CANSO). (2016). *Airport Collaborative Decision-Making: Optimisation through Collaboration, An Introductory Guide for Air Navigation Service Providers.*

312 ACI World. (2012). *CANSO and ACI Partner on Promoting A-CDM Implementation*. https://aci.aero/news/2012/06/14/canso-and-aci-partner-on-promoting-a-cdm-implementation/.

313 IATA. (2018). *Airline Airport Collaborative Decision Making Group (AACG) A-CDM Coordination.*

314 ICAO. (2018). *Manual on Collaborative Air Traffic Flow Management (ATFM)*. Doc 9971. 3rd Edition.

315 ICAO. (2019). *2016-2030 Global Air Navigation Plan*. Doc 9750. 6th Edition. https://www4.icao.int/ganpportal/.

316 Civil Air Navigation Services Organization (CANSO). (2019). *Guidelines on Airport-Collaborative Decision Making (A-CDM) Key Performance Indicators.*

317 Network Manager nominated by the European Commission. (2016). *Airport Capacity Assessment Methodology/ACAM Manual*. Edition 1.1. EUROCONTROL.

318 Network Manager nominated by the European Commission. (2018). *Airport Network Integration – Concept for Establishment of an Airport Operations Plan (AOP).* Edition 1.1. EUROCONTROL.

319 EUROCONTROL. (2016). *A-CDM Impact Assessment*. Final Report. Brussels, Belgium.

320 Le Bris, G. et al. (2021). *ACRP 10-27: Using Collaborative Decision Making to Enhance the Management of Adverse Conditions*. Transportation Research Board. National Academies. Washington, DC, USA.

321 Barco-Orthogon, Cambridge University and ENAC. (2014). *Multimodal, Efficient Transportation in Airports and Collaborative Decision Making*. Project Final Report. Grant Agreement 314453.

322 Folland, C.K., Karl, T.R., et al. (2001). *Observed Climate Variability and Change*. In Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the IPCC.

323 NOAA National Centers for Environmental Information. (2020). *State of the Climate: Global Climate Report for February 2020*. https://www.ncdc.noaa.gov/sotc/global/202002.

324 Bastin, J.F., et al. (2019). *Understanding climate change from a global analysis of city analogues*. In Plos One. https://doi.org/10.1371/journal.pone.0217592.

325 Le Bris, G. and Nguyen, L.-G. (2023). Airport Climate Vulnerability & Resilience Handbook. WSP USA.

326 Williams, P.J., et al. (1995). *Permafrost and climate change: geotechnical implications*. Philosophical Transactions of the Royal Society of London. Series A: Physical and Engineering Sciences 352. pp. 347–358. http://doi.org/10.1098/rsta.1995.0075.

327 NASA. (2013). *Severe thunderstorms and climate change*. https://climate.nasa.gov/news/897/severe-thunderstorms-and-climate-change/.

328 Cai, W., et al. (2014). *Increasing frequency of extreme El Niño events due to greenhouse warming*. Nature Climate Change 4, pp. 111–116. https://doi.org/10.1038/nclimate2100.

329 Silva Dias, P., et al. (2006). *The Catarina Phenomenon*. Meteorology Research Program Report Series. pp.329-360.

330 Zhong, S., et al. (2017). *The impact of climate change on the characteristics of the frost-free season over the contiguous USA as projected by the NARCCAP model ensembles*. Climate Research. https://doi.org/10.3354/cr01450.

331 Climate Central. (2020). *Coastal Risk Screening Tool, Land projected to be below tideline, annual flood level, and 10-year flood level in 2070.* Assuming moderate cuts in pollution, mid-range result from sea-level projection range (50th percentile) and the mid-range sea-level-projection per Kopp et al., 2014. Exclude currently protected areas per physical features. https://coastal.climatecentral.org/map/.

332 NOAA. (2020). *Sea Level Rise Viewer*. https://coast.noaa.gov/slr.

333 National Academies of Sciences, Engineering, and Medicine. (2018). *Critical Issues in Transportation 2019*. The National Academies Press. Washington. D.C. https://doi.org/10.17226/25314.

334 Voskaki, A. et al. (2023). The impact of climate hazards to airport systems: a synthesis of the implications and risk mitigation trends. *Transport Reviews*, 43(4). pp. 652–675. https://doi.org/10.1080/01441647.2022.2163319

335 Wampler, B. (2008). *When Does Participatory Democracy Deepen the Quality of Democracy? Lessons from Brazil*. Comparative Politics. Vol. 41. No. 1. pp. 61–81. JSTOR. www.jstor.org/stable/20434105.

336 Institute for Transportation & Development Policy. (n.d.). *What is BRT?*. https://www.itdp.org/library/standards-and-guides/the-bus-rapid-transit-standard/what-is-brt/.

337 Lindau, L. A., et al. (2010). *Curitiba, the Cradle of Bus Rapid Transit*. Built Environment (1978). JSTOR. Vol. 36. No. 3. pp. 274–282. www.jstor.org/stable/23289717.

338 ICAO. (2016). *Appendix F: Resolution A39-1: Consolidated statement of continuing ICAO policies and practices related to environmental protection – General provisions, noise and local air quality*. 39th Triennial Assembly.

339 ICAO. (2023). *Annex 16 to the Convention on International Civil Aviation*. Environmental Protection. Volume IV — Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). 2nd Edition.

340 ICAO. (2018). *Airport Planning Manual, Part 2 — Land Use and Environmental Control*. Doc 9184. 4th Edition.

341 ICAO. (2018). *Recommended Method for Computing Noise Contours around Airports*. Doc 9911. 2nd Edition.

342 ICAO. (2010). *Review of noise abatement research & development and implementation projects*. Doc 9888. 1st Edition.

343 ICAO. (2014). *Guidance on Environmental Assessment of Proposed Air Traffic Management Operational Changes* Doc 10031. 1st Edition.

344 ICAO. (2018). *Procedures for Air Navigation Services — Aircraft Operations (PANS-OPS).* Part I & II. Doc 8168. 6th Edition.

345 ICAO. (2010). *Continuous Descent Operations (CDO) Manual*. Doc 9931. 1st Edition.

346 ICAO. (2013). *Continuous Climb Operations (CCO) Manual*. Doc 9993. 1st Edition.

347 ICAO. (2012). *ICAO's Policies on Charges for Airports and Air Navigation Services*. Doc 9082. 9th Edition.

348 ICAO. (2020). *Airport Economics Manual*. Doc 9562. 4th Edition.

349 ATAG. (2017). *Flying in Formation: Air Transport and the Sustainable Development Goals*. 1st Edition.

350 Nordic Network for Electric Aviation. (2023). Accelerating the development of electric aviation in the Nordic countries. Nordic Innovation. https://norden.diva-portal.org/smash/get/diva2:1811595/FULLTEXT01.pdf

351 Cavicchia, R. (2024). Ten-year Regional Outlook: Future Perspective for Electric Aviation in the Nordic Region. Nordregio Report 2024:8. http://norden.diva-portal.org/smash/get/diva2:1844053/FULLTEXT01.pdf

352 Penner, J.E., et al. (1999). *Aviation and the Global Atmosphere*. In collaboration with the Scientific Assessment Panel to the Montreal Protocol on Substances that Deplete the Ozone Layer. Cambridge University Press. pp 373. UK.

353 EUROCONTROL. (2019, November 7–8). *Sustainable Skies Conference: Contrails in Focus* [Conference presentations]. Brussels, Belgium. https://www.eurocontrol.int/event/sustainable-skies-conference-contrails-focus

354 ICAO. (2019). *Resolution A40-19: Consolidated statement of continuing ICAO policies and practices related to environmental protection - Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)*. Assembly – 40th Session.

355 ICAO. (2019). *2019 ICAO CORSIA Regional Workshops*. Presentation Materials. https://www.icao.int/Meetings/RS2019/Pages/Presentations.aspx.

356 ICAO. (2016). *Introduction to the ICAO Basket of Measures*. ICAO Environmental Report.

357 American Association of Airport Executives (AAAE). (n.d.). *Airport Certified Employee (ACE)*. https://www.aaae.org/aaae/AAAEMBR/AAAEMemberResponsive/PD/Training/Onsite_Training/ACE_PROGRAMS.aspx.

358 McMahon, A. (2010). *Does Workplace Diversity Matter? A survey of Empirical Studies on Diversity and Firm Performance*. Journal of Diversity Management. Vol. 5. No. 2. pp. 37-48.

359 Lorenzo, R., et al. (2017). *The Mix That Matters Innovation Through Diversity*. The Boston Consulting Group. https://www.bcg.com/publications/2017/people-organization-leadership-talent-innovation-through-diversity-mix-that-matters.aspx.

360 ICAO. (2006). *Preamble, Convention on International Civil Aviation*. Doc 7300. 9th Edition.

361 Unmanned Airspace. (2019). New study details global urban air mobility costs, revenues and infrastructure requirements. https://www.unmannedairspace.info/urban-air-mobility/new-study-details-global-urban-air-mobility-costs-revenues-and-infrastructure-requirements/

362 Le Bris, G. and Nguyen, L.-G. (2023). An Airport & Vertiport/Aircraft Compatibility Approach of Electric Vertical Takeoff & Landing Aircraft Design. Vertical Flight Society, Forum 79. https://doi.org/10.4050/F-0079-2023-18060

THINKING THE FUTURE

Predicting the future of a fast-changing industry like aviation is needed to support long-term policymaking, strategic decision-making, and capital investments. From the early years of the jet age until the 1980s, work was primarily based on traditional forecasting, assuming a linear evolution of demand in a bipolar and predictable world. The impact of the 1979 airline deregulation in the United States and around the globe, and the subsequent acceleration of passenger demand throughout the 1980s and 1990s, warranted a new shared approach of long-term development. More recently, starting in the late 1990s, awareness on a growing number of emerging issues (many arising from global threats such as climate change and geopolitical events) reset the way the aviation community collectively planned for its long-term future.

This section presents a selection of publications and workshop initiatives on the future of airports that have shaped or influenced aviation decision makers and professionals at the national level. While the technical literature on the long-term future of aviation includes hundreds of publications, this selection focuses on airport-centric, multidisciplinary works, supported by proceedings or reports, that followed a systemic approach similar to the effort conducted under this project.

THE AIRPORT OF PARIS, ALAIN BOZEL (1944)

The Airport of Paris [L'aéroport de Paris] memorandum[a] was written during World War II by then-General Secretary to the Ministry of War of the Provisional Government of the French Republic, Alain Bozel,. It advocated creating a "model airport" near Paris, France, based on three arguments: commercial aviation would soon take over marine transportation, for both passengers and freight; specialized industries would be needed to build the aircraft; and becoming an aviation gateway would boost France's post-war economic development. The memorandum also anticipated future trends in air travel, such as the hub-and-spoke system and the need for efficient first- and last-mile transportation. After the war ended, French government created a public corporation that developed and operated the Greater Paris airport system.

CIVIL AVIATION RESEARCH AND DEVELOPMENT: AN ASSESSMENT OF FEDERAL GOVERNMENT INVOLVEMENT, NATIONAL ACADEMY OF ENGINEERING (1968)

The Aeronautics and Space Engineering Board of the National Academy of Engineering in the United States published the above titled report to advise the National Aeronautics and Space Administration (NASA), the U.S. Department of Transportation (USDOT), the Federal Aviation Administration (FAA), and other U.S. government agencies on identifying major existing and future issues restricting the growth of civil aviation, and to suggest coordinated measures to address these problems.[b] It made the following recommendations:

---

a Bozel, A. (1944). L'aéroport de Paris.

b National Research Council. (1968). Civil Aviation Research and Development: An Assessment of Federal Government Involvement: Economics of Civil Aviation. Washington, DC: The National Academies Press. https://doi.org/10.17226/20380

- Create a national plan for airport development to accelerate the growth of civil aviation. In response, the FAA created the National Airport System Plan, the forerunner of today's National Plan of Integrated Airport Systems.

- Conduct technical research on nine topics: airport capacity, runway/taxiway capacity, airport standards, baggage handling, passenger boarding bridges, cargo, general aviation, landside access, and ground transportation.

- Divide civil aviation research among three agencies along these lines:

- USDOT: systems studies to identify, analyze, and rank civil aviation goals, as well as the research and development needed to attain these goals.

- FAA: systems testing of the resulting operational concepts and hardware, in addition to operating the airspace network.

- NASA: conduct research and development in all the areas of importance to civil aeronautics.

AIRPORTS OF THE FUTURE, ACADÉMIE NATIONALE DE L'AIR ET DE L'ESPACE (1995)

The National Air and Space Academy in France organized an international symposium on Airports of the Future, focused on demand for air travel, improving operating capacity and efficiency, better integration of airports into their political and social environments, and design of new airports[c]. The symposium was held during a time of increasing passenger demand following deregulation and acknowledged the role of the airport infrastructure in supporting air travel growth. Noise was also termed the "Achilles heel" of air travel, as a key reason that expanding airport capacity becoming a very difficult, if not impossible, political problem. One speaker recommended a number of potential industry responses to this mismatch between demand and capacity expansion: aircraft with greater seating capacity, fewer airlines, use of smaller airports, construction of airports on harbor islands, and diversion of short-haul travel to other modes.

A LOOK INTO THE FUTURE OF AIRPORT PLANNING, DESIGN, AND CONSTRUCTION BY ANALYZING CURRENT ISSUES, NATIONAL ACADEMIES (2000)

As the part of a millennium paper series, the Transportation Research Board of the U.S. National Academies sponsored research on trends in the air transport industry and how these might impact future airport planning and design efforts[d]. Based on discussions with airport planners and engineers, the report identified the following trends: sustained growth in both passenger and cargo air transport, the rise in public-private partnerships (P3) as an alternative to government-run projects, and global economic growth. All of these trends have continued. The report also identified four future issues:

- Increased air traffic and insufficient air navigation resources with concerns about potential increases in flight delays.

---

c Académie Nationale de l'Air et de l'Espace. (1996). L'aéroport du futur – L'essor et l'efficacité du transport aérien seront-t-ils contraints par la capacité des aéroports? Paris (France), November 15-17, 1995.

d Fife, W. and McNerney, M. T. (1999). A Look into the Future of Airport Planning, Design, and Construction by Analyzing Current Issues. TRB A1J07: Committee on Aircraft/Airport Compatibility.

- Development of larger commercial aircraft types required amendments to airport design standards—including their applicability to existing airports—and safety assessments for wake turbulence separation.

- Environmental elements, such as air quality, aircraft noise, energy efficiency, and National Environmental Policy Act compliance.

- The effects of new technologies for air navigation, security, efficiency, and passenger experience enhancement.

AIRPORTS AND THEIR CHALLENGES, ACADÉMIE DE L'AIR ET DE L'ESPACE (2009)

In October 2009, the Air and Space Academy in France held a conference in Paris to discuss current and future airport challenges. This conference could be seen as a follow-up to the international symposium organized by the same institution nearly 15 years earlier.

The main themes of the conference were airport capacity and delay, customer experience, ground access and airport cities, sustainable development, and passenger services. It tackled issues such as airport privatization, intermodality, collaborative decision making, security measures since 9/11, and baggage handling. The recommendations expressed in the minutes of the conference urge Europe to pursue air traffic management modernization (Single European Sky ATM Research). However, while the document acknowledged climate change and advocated for greenhouse gas-efficiency, the discussions failed short to promote any net-zero aspirational goal, talking instead about minimizing emissions.[e]

THOUGHT LEADER FORUM—EMERGING ISSUES FOR ACRP, NATIONAL ACADEMIES (2018)

Airport Operations Committee for the Airport Cooperative Research Program of the Transportation Research Board brought together industry leaders in this Thought Leader Forum (Forum) to discuss emerging issues of national interest to airports within the next 5 to 10 years. The goal of the Forum was to identify and define high-level emerging critical issues that impact, or will soon impact, the airport industry. The Forum identified seven top emerging topics: total customer experience; challenges and opportunities for the airport business model; impacts of emerging and innovative technologies; airport sustainability; enhancing resiliency of airports and interrelated systems; airport workforce development; and enhancing the aviation ecosystem.[f]

e Académie de l'Air et de l'Espace. (2010). Les Aéroports face à leurs défis. Dossier 33.

f National Academies of Sciences, Engineering, and Medicine. (2019). Thought Leader Forum Summary—Emerging Issues for ACRP. Washington, DC: The National Academies Press. https://doi.org/10.17226/25441

WORKSHOP ON AIRPORT ELECTRIFICATION AND AUTOMATION FOR EMERGING AERIAL MOBILITY, NATIONAL ACADEMIES (2022)

The 2022 Transportation Research Board Annual Meeting featured a workshop on Airport Electrification and Automation for Emerging Aerial Mobility. This workshop discussed how airports are at the threshold of several transitions and breakthroughs that will change the face of aviation, affect the way people travel by air, and impact communities and businesses. The innovations considered during the discussions include advanced air mobility, electric and hydrogen aircraft, artificial intelligence and machine learning, automation, and mobility-as-a-service. The workshop goals were to discuss airport/aircraft compatibility issues regarding advanced air mobility (AAM) and other emerging airside/airspace users (e.g., supersonic aviation, commercial space transportation, etc.); identify policy needs to accommodate new aerial mobility at airports, address the needs of the state departments of transportation, develop adequate technical standards; educate attendees on the upcoming challenges of accommodating new aerial mobility at airports; and identify research needs and topics on new air mobility.

FUTURE OF AVIATION, ACRP INSIGHT EVENT, NATIONAL ACADEMIES (2022)

During this two-day event, participants discussed airports' current and future challenges in all realms: operational (facilities and infrastructure), market (air services) and social and environmental trends. The renaissance of supersonic air travel, the introduction of alternative fuels for aircraft (sustainable aviation fuels, electricity, and hydrogen), and the introduction of AAM were all discussed, as was the need to provide the required infrastructure to cater to those changes. Although the threat of climate change has been a catalyst to research and implement emission reduction strategies, many airports still do not have holistic, comprehensive adaptation and mitigation plans to address climate change. Participants also discussed the contactless passenger experience during COVID-19 as a stepping-stone to a more integrated, hassle-free travel experience, technological improvements that expedite security controls, and the needs for further airside concessions as airports increasingly become shopping centers. Finally, airport managers need to emphasize staff training and retention.[g]

FUTURE OF AVIATION, UC BERKELEY (2022)

This conference focused on implementation and policymaking around AAM, which has economic, environmental, and social dimensions. Discussions included technological (safety and security) aspects as well as effective community engagement and equity generation through AAM (University of California, Berkeley 2022). As the first step toward community acceptance of a new technology is ensuring that it is safe, discussions on enhancing the safety of AAM operations considered the role of automation, alternative propulsion mechanisms, and aircraft piloting

g National Academies of Sciences, Engineering, and Medicine. (2022). The Future of Aviation. Washington, DC: The National Academies Press. https://doi.org/10.17226/26813 arrangements, as well as security, including cybersecurity, potential misuse of AAM, and passenger screening and identification techniques.

The positive contributions that AAM can bring to the communities it serves were also discussed. Strategies to promote AAM as part of a multimodal network, including repurposing existing transport infrastructure for AAM operations and integrating it with other on-demand mobility services, were explored. The use of alternative fuels can help achieve aviation's net-zero emissions target. AAM can also spur development and job creation with vertiport-centric development as a viable pathway to community revitalization, while pursuing an equity-driven approach.

LESSONS LEARNED FROM PREVIOUS LONG-TERM FUTURE PLANNING EXERCISES

Industry-led futuring exercises and papers with a holistic and systematic approach to long-term issues recurred frequently during the 1990s. Facing a capacity crush due to the rapid expansion of aviation, stakeholders in North America and Europe organized workshops to share perspectives about the next decades. The typical horizon for these discussions was 10 years, with a few conversations pushing to 2030. The main priority was to address the immediate need to accommodate fast-growing passenger demand despite limited capacity at hub airports. Most of these efforts adequately predicted the democratization of air travel in the aftermath of deregulation, and they successfully identified governance, funding, infrastructure, and noise concerns as limits to air travel growth. The key solutions (airport privatization and P3, more-stringent noise standards for aircraft, air traffic management modernization [NextGen and SESAR], and the introduction of larger aircraft between hubs and city pairs of interest) have been implemented and have helped overcome these difficulties.

However, most of the futuring aviation exercises and papers of the 1990s did not anticipate or adequately acknowledge trends that are important now. For instance, capacity and delay were widely discussed, but operational resiliency, at the center of so much attention in the post-COVID-19 era (Wolchansky & Le Bris, 2021), was mostly absent from the conversation. Also, climate change is often mentioned as a topic requiring further study, but it was inadequately addressed until very recently. The lack of ethnic, generational, gender, national, and professional diversity of the panels involved in these thought leadership process may have contributed to the difficulties of radically thinking outside of the box. Such events cannot seriously claim to represent the future of aviation if attendance does not reflect the diversity of the broader aviation community.

It took three massive crises to change the lack of ethnic, generational, gender, national, and professional diversity. First, the 1999 IPCC report on Aviation and the Global Atmosphere was a revelation for the aviation community, and climate change was added to the overall agenda in the early 2000s. Second, the 9/11 terrorist attacks required airports and their stakeholders to implement demanding, rigid security standards and processes in a very short period of time, Moreover, it became clear that traditional futuring, which assumes the continuation of the status-quo, could not address the complexity of a changing world, and that aviation itself could be subject to unpredictable and far-reaching events. Third, while we do not know how future generations will reflect upon the COVID-19 pandemic, the late 2010s and early 2020s may well be seen as a pivotal moment in the history of aviation.

The amplitude and diversity of emerging issues and potential breakthroughs that could affect aviation is unprecedented. Social and climate justice are also reconnecting the long-term development of aviation systems with communities that are either impacted by the negative externalities of aviation or underserved by it. The challenges of the past have not entirely receded, and the list of potential future challenges may be equally long.

TABLE 3. CURRENT EXAMPLES AND TRENDS ON AIRPORT BUSINESS MODELS

AIRPORT BUSINESS MODEL	STATUS	EXAMPLES	TRENDS
PRIVATE COMPANIES	Majority Private Shareholding Corporations	ACSA, ADR, Aeropuertos Argentina 2000, Aéroports de la Côte d'Azur, Aéroports de Lyon, Aéroport Toulouse-Blagnac, ASUR, Auckland International Airport Limited, Australia Pacific Airports Corporation, AvPorts, Edeis, Ferrovial, GMR, Grupo Aeroportuario del Pacífico, GRU Airport, SOCICAM Aeroportos, Sydney Airport Holdings, Vinci Airports, Voa São Paulo	This model has been growing since the 1980s. Private airport management groups include firms founded by investors, and former public operators sold by their governments to private interests. Both seek concessions of airports, or PPP with local governments.
TOWARD CORPORATIZATION	State-Owned Companies	ADAC, AENA Aeropuertos, Airports of Thailand, Airports Corporation of Vietnam, Avinor, Bahrain Airport Company, Capital Airport Holding, Changi Airport Group, Dubai Airports Company, Finavia, Groupe ADP, Isavia, Malaysia Airports, Schiphol Group, Swedavia	Many former governmental agencies or companies became autonomous state-owned companies in the years 1980 to 2010. Most of the time, central governments still own a majority shareholding. The question of maintaining ownership is raised in some of these countries with governments reconsidering their role. Their degree of autonomy authorizes them to pursue concessions outside of their historical airports and export their expertise.
	Local government-Owned Companies	Flughafen München, Flughafen Zürich AG, Fraport, Manchester Airport Holdings	In Germany and Switzerland, the federal system promoted a development of airports by the local governments. Later, operators followed a similar process than central government-operated airports and became incorporated with a majority shareholding from local authorities. Their degree of autonomy authorizes them to chase concessions outside of their historical airports and export their expertise.
	Non-For-Profit	ADM, GTAA, YQB	This status is particularly popular in Canada as an alternative to Airport Authorities.

AIRPORT BUSINESS MODEL	STATUS	EXAMPLES	TRENDS
PUBLIC ENTITIES	Public Companies	ACITA (State of Coahuila), Aeropuertos y Servicios Auxiliares, EGSA/Alger, EGSA/Oran, EGSA/Constantine, EHCAAN, Infraero, ENANA-EP, ONDA, Régie des voies aériennes	This model, which was common in Europe in the years 1950 to 1980, is now limited to few operators in the world (mostly in Africa, Central Asia, Middle East, Latin America). Public companies are chartered by governments or parliaments. They are not incorporated. Management typically answers to the Department of Transportation. Employees are public workers or similar status.
	Port Authorities	AAI, AAJ, Kenya Airports Authority, MWAA, Port Authority of New York and New Jersey	This model is popular in the United States to move airport management toward more independence from the political agendas of local governments.
	Governmental Aviation Departments	Alaska DOT, Civil Aviation Authority of Mongolia, DAESP, DEN Airport, GACA, LAWA, MDAD, SAAS	We observe a transition of the business models of Aviation Departments toward concessions and other PPP for the larger airports. Smaller, community-service airfields are operated by local governments.

TABLE 4. SELECTION OF PHYSICAL ATTACKS ON AIRPORTS AND AIRPLANES

YEAR	AIRPORT	DESCRIPTION	PATTERN
1975	SGN	MANPADs hit a Douglas C-54D-5-DC in Vietnam flying from Vientiane to Saigon (now Ho Chi Minh City). Six crew members and 20 passengers were killed in the crash.	MANPAD
1978	Enroute VFA-SBY	MANPADs hit an Air Rhodesia Vickers 782D Viscount passenger airline by the Zimbabwe Peoples Revolution Army. Four crew members and 34 of the 56 passengers were killed in the crash.	MANPAD
1979	IAD	Bomb planted by Unabomber in the cargo hold of Boeing 727, operated by American Airlines, exploded forcing an emergency landing. Twelve passengers were injured.	Bombing
1982	ESB	Bombing and shooting in the middle of a check-in area at Ankara Esenboğa Airport. The attack killed 9 people and injured 72 others.	Firearm attack in terminal
1983	ORY	Bombing of Turkish Airlines Check-in counters at Orly Airport by Armenian militants. The explosion killed eight people and injured 55.	Terminal bombing
1984	LHR	Bombing at baggage claim of Terminal 2. Twenty-two out of the 60 people present were injured.	Terminal bombing
1985	FRA	Bombing at the international departure lounge in Frankfurt Airport by Palestinian group with Libya complicit. The attack killed three people and wounded 74 other others.	Terminal bombing
1985	NRT	Bomb planted by Sikh separatists intended for Air India Flight 301 exploded during baggage handling operations. Two baggage handlers were killed, and four of them were injured.	Terminal bombing
1985	FCO	Detonated hand grenades and opened fire at people queuing in front of the check-in of El-Al airlines (Palestinian-nationalists). Sixteen people were killed and 99 wounded.	Firearm attack in terminal
1985	VIE	Detonated hand grenades and opened fire at people queuing in front of the check-in of El-Al airlines. Two people were killed and 39 wounded.	Firearm attack in terminal
1986	GMP	Bomb explosion outside a terminal building at Gimpo International Airport by North Korea. Five people were killed and 36, injured.	Terminal bombing

YEAR	AIRPORT	DESCRIPTION	PATTERN
1988	AGA	MANPADS hit two Douglas DC-7 from Senegal to Morocco by POLISARIO militants in the Western Sahara on approach to Morocco. One DC-7 crashed killing all five crew members. The other DC-7 landed safely in Morocco.	MANPAD
1993	SUI	MANPADs hit a Tupolev 154B operated by Transair Georgia by Abkhazian separatist forces as it was approaching Sukhumi-Babusheri Airport. It crashed onto the runway and caught fire, killing 108.	MANPAD
1994	ALG-MRS	Armed Islamic Group of Algeria hijacked Air France Flight 8969. Three passengers were murdered.	Hijacking airliner
1994	KGL	MANPADs hit a Dassault Mystère-Falcon 50 executive jet on final approach to Kigali. Aboard the jet were the Presidents of Rwanda and Burundi and its French flight crew. The attack killed all aboard and sparked massive ethnic violence and regional conflict.	MANPAD
1996	REU	Euskadi Ta Askatasuna planted two bombs in a rubbish bin that detonated in the passenger terminals. Thirty-five people were injured.	Terminal bombing
1998	KND	MANPADs hit a Boeing 727-30 Lignes Aeriennes Congolaises airliner just after take-off from Kindu Airport by Tutsi militia. The attack killed all three crew members and 38 passengers.	MANPAD
1998	JAF	MANPADs shot by Liberation Tigers of Tamil Eelam terrorists hit an Antonov An-24RV, operated by Lionair, off the coast of Sri Lanka after take-off from Jaffna-Palaly Air Base. The attack killed all 7 crew members and 48 passengers.	MANPAD
1998	NOV	MANPADs hit a United Nations-chartered Lockheed C-130 Hercules transport over Angola flying from Huambo to Saurimo by UNITA forces, killing 14.	MANPAD
1999	NOV	MANPADs shot by UNITA forces hit a United Nations-chartered Lockheed C-130 Hercules transport a few minutes after take-off from Huambo. All four crew members and five passengers were killed.	MANPAD

YEAR	AIRPORT	DESCRIPTION	PATTERN
2001	United States of America	A series of four coordinated terrorist attacks by Al-Qaeda. Four passenger planes were hijacked. Two of the planes crashed into the World Trade Center complex, a third crashed into the Pentagon, and the fourth crashed into a field in Stony Creek Township. 2,996 people were killed and over 6,000 were injured.	Hijacking airliner
2001	Enroute CDG-MIA	A failed bomb attempt by Al-Qaeda to detonate explosives hidden in his sneakers on American Airline Flight 63. Passengers thwarted his plan, and the plane landed safely in Boston. No casualties.	Plane bombing
2001	CMB	Tamil Tigers attacked air force planes. All 14 attackers were killed, along with six Sri Lankan air force personnel and one civilian. Twelve soldiers were injured, along with three Sri Lankan civilians and a Russian engineer. No tourists were harmed during the attack. Five SriLankan Airlines aircraft were destroyed.	Firearm attack
2002	MBA	MANPADs hit an Arkia Airlines Boeing 757-3E7 with 271 passengers and crew as it took off from Mombasa, Kenya by terrorists. Both missiles missed.	MANPAD
2002	LAX	Radicalized individual (Palestinian nationalist) active shooter opens fire at the El Al ticket counters. Two people were killed and four others were injured.	Active shooter
2003	BGW	MANPAD hit a DHL Airbus A300B4 cargo jet transporting mail shortly after take-off from Baghdad International airport. Though hit in the left fuel tank, the plane was able to return to Baghdad airport and land safely.	MANPAD
2006	MAD	Van bomb explosion in Terminal 4 parking area (ETA). The attack damaged the airport terminal, destroyed the entire parking structure, and killed two people and injured 52 others.	Parking bombing
2007	MGQ	MANPADs hit an Ilyushin 76TD cargo plane shortly after take-off from Mogadishu International. The attack killed the crew of 11.	MANPAD

YEAR	AIRPORT	DESCRIPTION	PATTERN
2007	GLA	Car loaded with propane canisters was driven at the glass doors of the Glasgow Airport terminal and set ablaze. It rammed into passengers. Five people were injured and one of the perpetrators died.	Vehicles ramming
2007	JFK	Aborted Islamic Terrorist plot for bombing a system of jet fuel supply tanks and pipelines that feed fuel to JFK. No casualties.	Airport bombing
2009	Non-airport location, Saudi Arabia	Body Cavity Bomb (BCB) attack against bin Nayef (SIIED), who was injured.	Active shooter
2009	CMB	Air attack with GA aircraft used as flying bombs by Tamil Tigers targeting military facilities in and around Colombo, Sri Lanka. Two people died and over 50 were injured.	Aerial attack with GA
2011	FRA	Active shooter opened fire at USAF bus parked outside a terminal building. Radicalized individual (AQ). Two people were killed and two other injured.	Active shooter
2011	DME	Suicide bombing by North Caucasus groups in the international arrival hall of Moscow's Domodedovo International Airport. 37 people were killed and 173 injured.	Terminal bombing
2012	PEW	At least five rockets were fired toward the airport by Taliban extremists. Three of those landed within the facility and two hit nearby residential areas. Militants then rammed a car bomb into the perimeter wall, sparking a firefight with troops posted nearby. Nine people were killed.	Firearm attacks
2013	PEK	Individual tries to kill himself with explosives. The explosion only injured the bomber.	Terrorism
2013	ICT	Failed bombing attack by radicalized individual (AQ) with the intention of detonating a car bomb. No causalities.	Terminal bombing
2014	KHI	Ten Taliban extremists attacked the cargo terminal of the Jinnah International Airport with automatic weapons, hand grenades, rocket-propelled grenades, and other explosives. Thirty-six people were killed and 18 injured.	Firearm attack
2014	DOK	Destruction by civil war. Pro-Russian separatist insurgents captured the terminal building of Donetsk International Airport. Paratroopers launched an assault on the airport, accompanied by airstrikes against insurgent positions	Act of War

YEAR	AIRPORT	DESCRIPTION	PATTERN
2015	SAW	Bombing by Kurdish nationalists in the apron area of Sabiha Gökçen International Airport. One person was killed, and one was injured.	Terminal bombing
2015	KDH	Attack and bombing by Taliban extremists at Kandahar Airfield (joint-use airport). Sixty-one people (11 attackers) died and at least 35 were wounded.	Firearm attack and bombing
2016	BRU	Two suicide bombers (ISIS) attacked a departure hall at Brussels Airport. The attack killed 32 civilians and three terrorists, and more than 300 people were injured.	Terminal bombing
2016	ISL	Two assailants (ISIS) approached a security checkpoint and opened fire before detonating the bombs they were carrying. Three attackers and 45 people were killed. More than 230 people were injured.	Firearm attack and bombing
2017	FNT	Radicalized individual (AQ) stabbed a police agent in the neck at Bishop International Airport. Police agent survived the attack.	Terrorist attack
2017	FLL	Active shooter opened fire near the baggage claim in Terminal 2. Five people were killed while six others were injured.	Active shooter
2017	ORY	Radicalized individual fails seizing weapon from a soldier of the Sentinelle operations. The individual was killed.	Firearm attack
2017	KUL	Kim Jong-nam (brother of North Korean dictator Kim Jong-Un) was murdered with VX nerve agent near an airport self-check-in kiosk. The Democratic People's Republic of Korea regime likely ordered the assassination.	Chemical weapon
2019	AHB	Houthi rebels launched drone and missile attacks on a touristic Saudi civilian airport. One person was killed and several others were wounded.	Act of War
2021	KBL	A suicide bombing occurred at Kabul's Hamid Karzai International Airport on August 26, 2021, amid the evacuation from Afghanistan. The attack resulted in the deaths of at least 183 individuals, including 170 Afghan civilians and 13 members of the United States military. The Islamic State – Khorasan Province (ISIS–K) claimed responsibility for the attack.	Suicide bombing

YEAR	AIRPORT	DESCRIPTION	TARGET(S)
2013	ISL	Access to the passport control system used at the international departure checkpoint was blocked by an alleged cyber-attack on July 26. Passengers stood in lines for hours and plane departures were delayed.	Passport Control System
2015	WAW	Around 1,400 passengers of the Polish airline LOT were grounded at Warsaw's Chopin airport after hackers attacked the airline ground computer systems used to issue flight plans.	Airline System
2016	BKP	Malware used to attack 3 Ukrainian energy providers was detected in a computer of the IT network of Kyiv's main airport (Boryspil). This network connects to air traffic control systems as well.	Energy Management
2016	HAN/SGN	Hackers successfully pulled-off cyberattacks against Vietnam's two largest airports and Vietnam Airlines. The attacks were attributed to a Chinese hacking group known as 1937CN. The government reported that hackers failed to cause any significant security issues or air traffic control problems.	Flight information Screens
2018	ATL	Hartsfield-Jackson Atlanta International Airport shut off its internal Wi-Fi network as a security measure as the City of Atlanta's network underwent a ransomware attack. ATL switched off the Wi-Fi service to avoid any malicious ransomware spreading to airport authority computers, airline computers, and possibly customers' computers.	IT systems Airport Wi-Fi
2018	BRS	A cyberattack caused flight information screens to fail for two days. A spokesperson said the displays were ultimately taken offline as a precautionary measure to contain the attack, which has been described as similar to a ransomware. The airport temporarily displayed departure times to passengers off whiteboards.	Flight Information System
2018	MHD	Monitors at an airport in Iran were reportedly hacked in protest of the Iranian government. The messages on the screens at Mashhad's airport denounced Iranian casualties in regional conflicts.	Flight Information System
2019	CLE	Cleveland Hopkins International Airport suffered a ransomware attack that affected the airport's email and information systems. The attack did not impact flight operations, but it disrupted certain administrative functions.	Flight Information System

TABLE 5. SELECTION OF CYBER-ATTACKS ON AIRPORTS

YEAR	AIRPORT	DESCRIPTION	TARGET(S)
2020	CPT	Cape Town International Airport in South Africa experienced a cyberattack that targeted its information systems. The attack disrupted certain airport operations, including flight schedules and passenger processing.	Flight Information System
2020	MAN	Manchester Airport in the UK experienced a cyberattack that targeted its IT systems. The attack disrupted certain airport operations, including flight information display systems.	Flight Information System
2020	SFO	Two login portals were hacked, leading to the theft of usernames and passwords. This breach was attributed to Russia's Energetic Bear group, targeting primarily U.S. infrastructure. The airport took down the affected websites, SFOConnect.com and SFOConstruction.com, and prompted users to change their passwords as a precaution.	Airport Website
2022	U.S. Airports	Over a dozen airport websites, including New York's LaGuardia and Chicago's O'Hare International, were temporarily brought down by distributed denial of service (DDoS) attacks from the Russian hacker group Killnet. These attacks primarily caused flight delays and cancellations, showing how cyber incidents can significantly disrupt operations even without stealing data.	Airport Website
2023	LGB	LGB was the target of a cyberattack affecting the airport's main website. The airport took the website offline temporarily to address the issue.	Airport Website
2023	DUB	Nearly 2,000 staff members of data, the operator of Dublin Airport, had their pay and benefits information compromised due to a cyberattack on Aon, a third-party professional service provider.	Personal Information of Airport Employees
2023	Various German airports	Several German airports, including Düsseldorf, Nüremberg, Erfurt-Weimar, and Dortmund, reported website outages attributed to possible hacker attacks. The disruption was suspected to be the result of large-scale DDoS attacks, though air traffic was not affected.	Airport Website
2024	BEY	Beirut–Rafic Hariri International Airport in Lebanon was the target of hackers that successfully compromise the flight information display systems to criticized Hezbollah.	Flight Information System

This case example illustrates how stakeholders can tackle together significant operational safety challenges in a reduced timeframe and cost-efficiently with a risk-based approach.

Prior to the mid-2010s, standards and practices in operational safety during airfield construction were deficient. The International Civil Aviation Organisation (ICAO) Standards and Recommended Practices feature very few provisions on this matter.[a] One of them (Pattern A for displaced threshold) can actually be confusing. Few countries (Australia, United States) have local standards. Some of them are still a potential source of accidents.[b c]

In 2009, Chicago O'Hare Intl. Airport (ORD) and John F. Kennedy Intl. Airport (JFK) prepared for runway construction projects involving a temporarily shortened runway with a displaced threshold. Despite a long preparation with the stakeholders and a detailed safety risk assessment with a mitigation plan going beyond the standards, serious incidents happened.[d] In 2011, Paris-Charles de Gaulle (CDG) performed a comprehensive safety risk assessment for a similar configuration to be implemented the next year. The initial search for previous incidents revealed a tremendous number of precursors all around the world and highlighted the lack of a standardized approach for mitigating the related risks.[e]

Research efforts were quickly initiated to correct these deficiencies. The two groups met in Paris in 2011. They shared their views and mutually benefited from their lessons learned. They have maintained contact since then. In the United States, the Federal Aviation Administration (FAA) developed an orange construction signage[f] and new standard layouts for markings that are now featured in AC 150/5370-2G. In Europe, Paris-CDG evaluated different messages for these signs[g], and developed various safety devices within the Infrastructure Workgroup of The French-Speaking Airports (UAF&FA). Both sides worked on enhanced phraseology and dissemination of the aeronautical information to the cockpit.

In September 2016, the Infrastructure Workgroup of The French-Speaking Airports released the initial version of its guidebook on Markings and Signage During

a ICAO. (2022). Displaced thresholds (5.2) and Runway closure markers (7.1). In Annex 14 to the Convention on International Civil Aviation. Volume I – Aerodrome Design and Operations. 9th Edition.

b Australian Transport Safety Bureau. (n.d.). Aviation safety investigations & reports Airbus A340 ZS-SLA. Investigation No 200501819.

c Australian Transport Safety Bureau. (2009). Operational non-compliance at Perth Airport, WA on 9 May 2008. Transport Safety Report (Final). AO-2008-033.

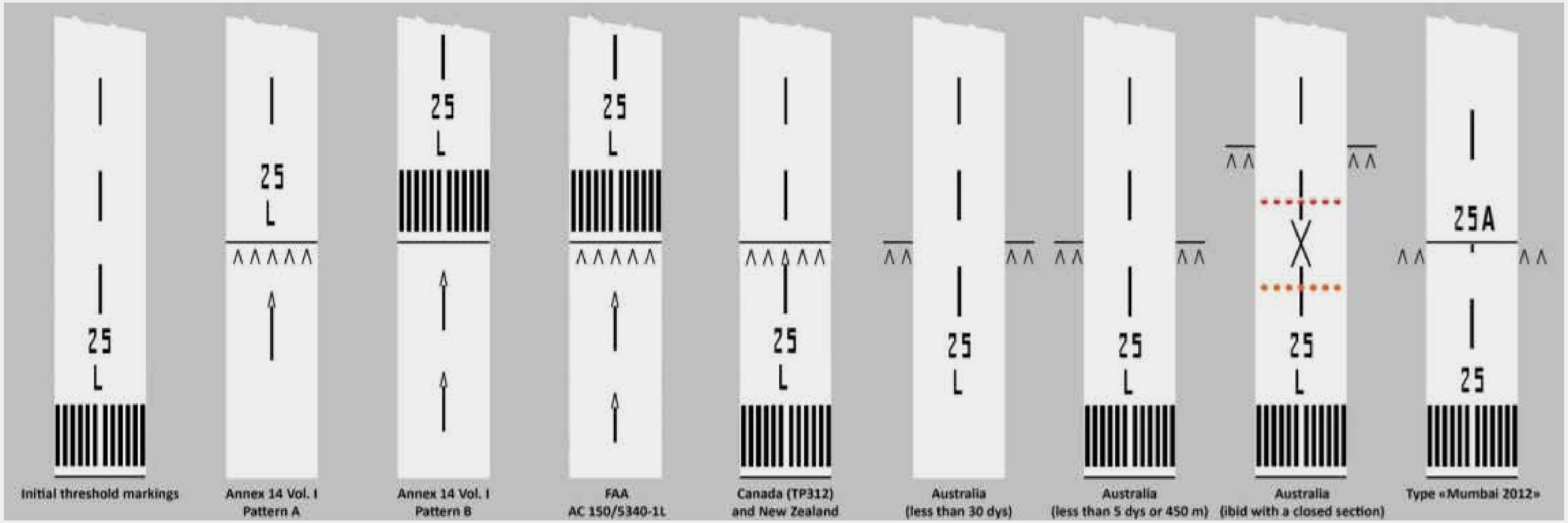
d Rosenkrans, W. (2009). What's on Your Runway? Lessons Learned During RWY28 Threshold Relocation at ORD. AeroSafety World. Flight Safety Foundation.

e Le Bris, G. (2013). Working Safely on an Operative Runway. AeroSafety World. Flight Safety Foundation.

f Bassey, R. (2015). Development and Evaluation of Safety Orange Airport Construction Signage. FAA.

g Berlucchi, R., Le Bris, G. and Siewert, D. (2016). Enhanced airfield signage to improve situational awareness in the vicinity of construction works. HindSight No 23. EUROCONTROL. Brussels. Belgium.

FIGURE 36. STANDARDS AND PRACTICES ON TEMPORARILY DISPLACED THRESHOLD MARKINGS



Airfield Construction[h]. This publication provides comprehensive guidance on markings and signage, lessons learned on the information of the airfield users, and best practices in safety risk management and stakeholder involvement. Plates propose comprehensive safety mitigation systems combining obliteration of existing items non-applicable during construction and the creation of temporary visual aids. They cover 20 situations including runway, taxiway, helipad, and service roads. Most importantly, they propose a mature configuration for temporarily shortened runways and runway closures. They introduce innovations such as color runway closure markers, mobile runway closure markers, and the orange construction sign.

In 2017, the European Action Plan for the Prevention of Runway Incursions V3.0 featured a new Appendix L on Maintenance, Inspections, Works in progress and Temporary Modifications of the Aerodrome that referenced the guide of The French-Speaking Airports and presented some of its signature mitigation–including the orange construction sign[i]. The same year, the French national aviation authority

h Infrastructure WG of The French-Speaking Airports (UAF&FA). (2017). Markings and Signage during Airfield Construction [Marquages et signalization temporaires (chantier)].

i EUROCONTROL, et al. (2017). European Action Plan for the Prevention of Runway Incursion. Brussels. Belgium.

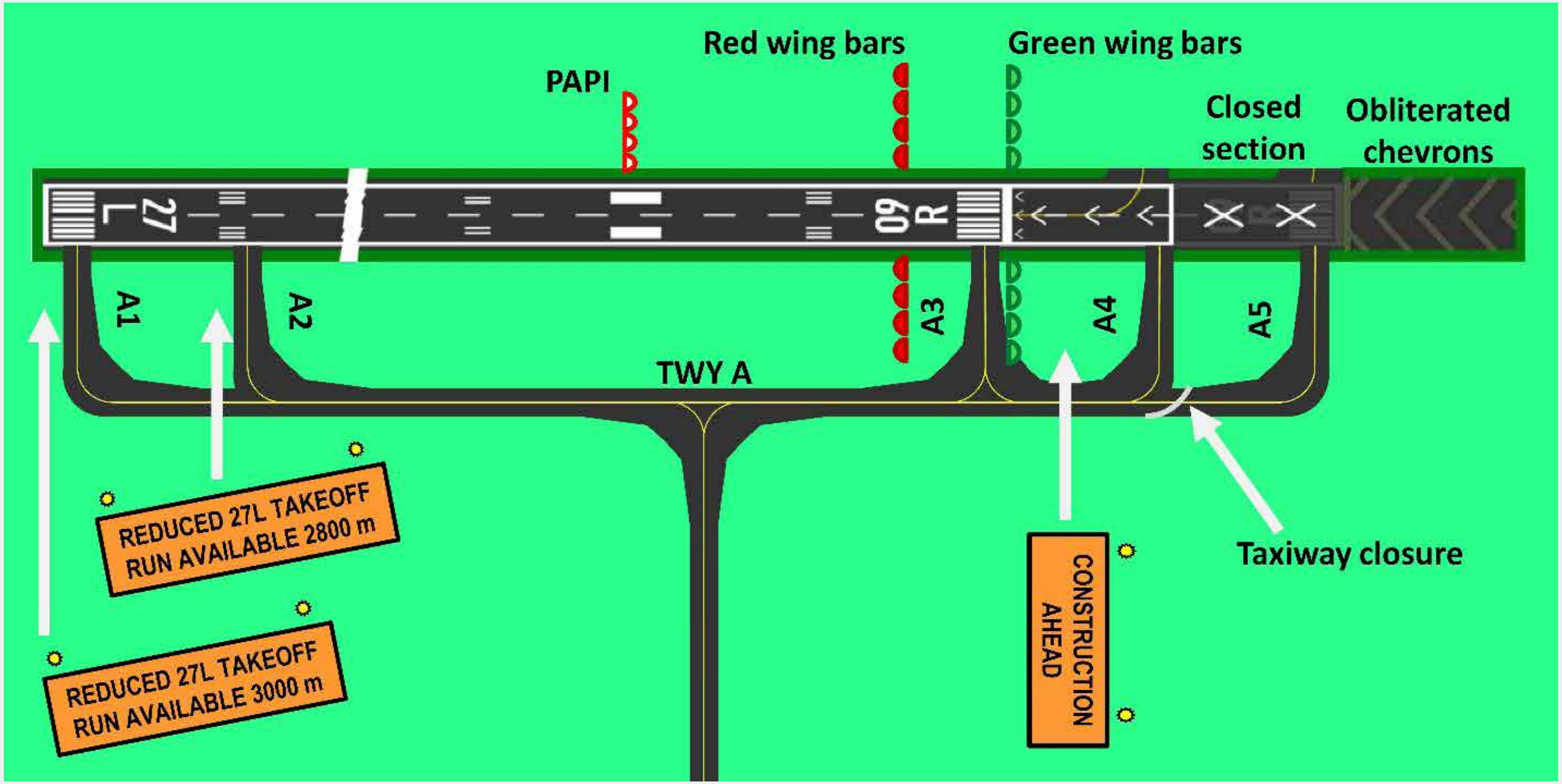


FIGURE 37. SAFETY DEVICES RECOMMENDED FOR TEMPORARILY DISPLACED THRESHOLDS BY THE INFRASTRUCTURE WORKGROUP OF THE FRENCH-SPEAKING AIRPORTS (UAF&FA)

(DGAC) discussed it during the National Symposium on Runway Construction Safety[j]. In 2018, Airports Council International (ACI) published the most important items of the guide in its guidebook on Managing Operations During Construction[k]. Most of the safety items were adopted by Agência Nacional de Aviação Civil (Brazil) in its new Manual of Maintenance and Airfield Construction[l].

j DGAC/DSAC. (2017). Travaux sur Pistes – Construire Ensemble la Sécurité.

k ACI. (2018). Managing Operations During Construction Handbook. http://www.aci.aero/Publications/Safety-Security-Operations/Managing-Operations-During-Construction-Handbook.

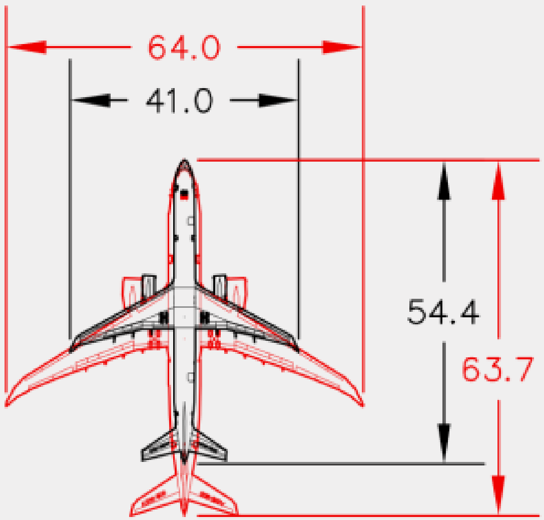
l ANAC. (2020). Manual de Obras e Serviços de Manutenção. 3rd Edition.

In 2020, the Infrastructure Workgroup of The French-Speaking Airports will revise the guidebook to take into consideration the Amendment 14 to the Annex 14 and subsequent update of national and regional standards (e.g., CS-ADR-DSN Issue 4 or the coming FAA Draft AC 150/5300-13B). They will also introduce novelties such as the built-in lighted “X” runway closure lighting system. It will also prepare an action plan to disseminate best practices in the less developed regions of the world.

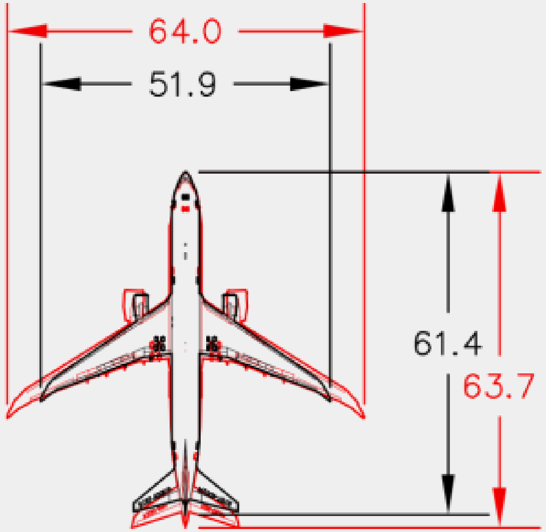
FIGURE 38. IMPROVING OPERATIONAL SAFETY DURING AIRFIELD CONSTRUCTION

APPENDIX F

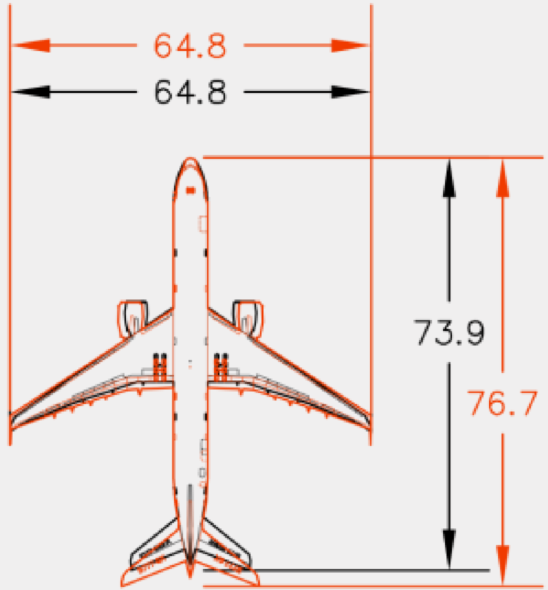
PHYSICAL CHARACTERISTICS OF AIRLINERS CURRENTLY IN SERVICE



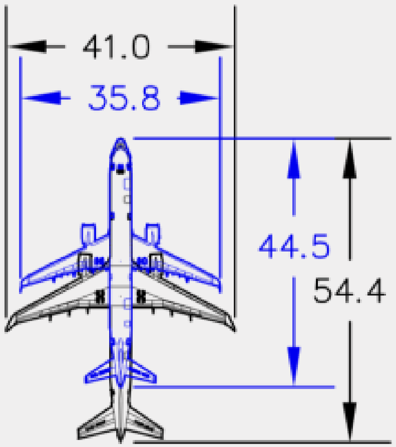
A330-900 vs 757-300W



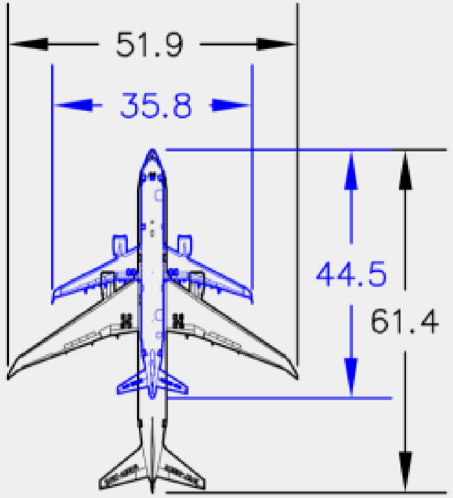
A330-900 vs 767-400ER



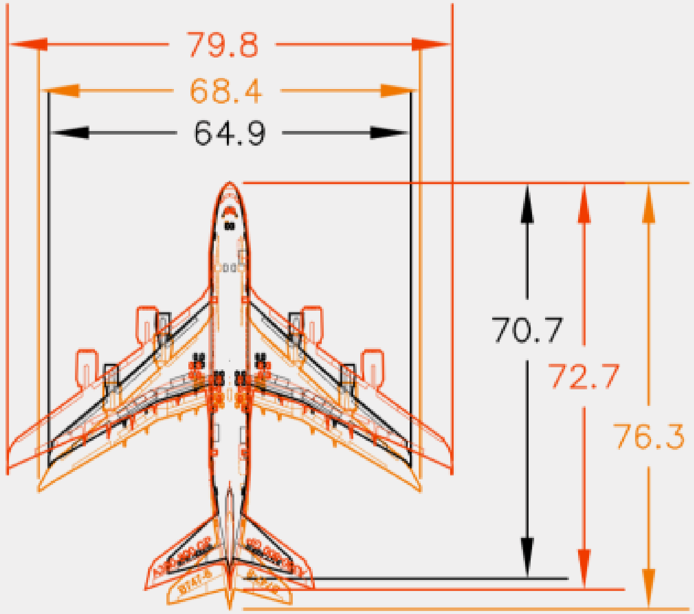
777-9 vs 777-300ER



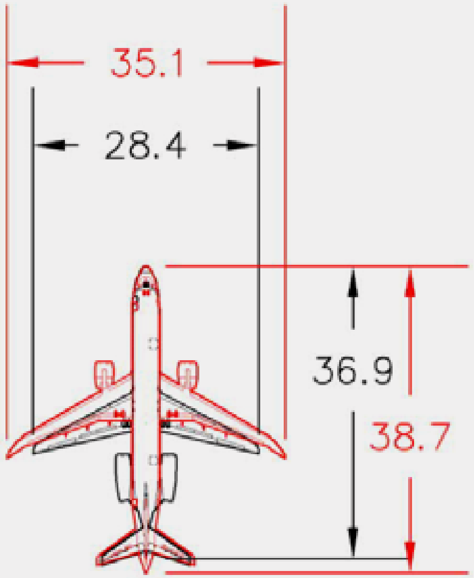
A321NEO vs 757-300W



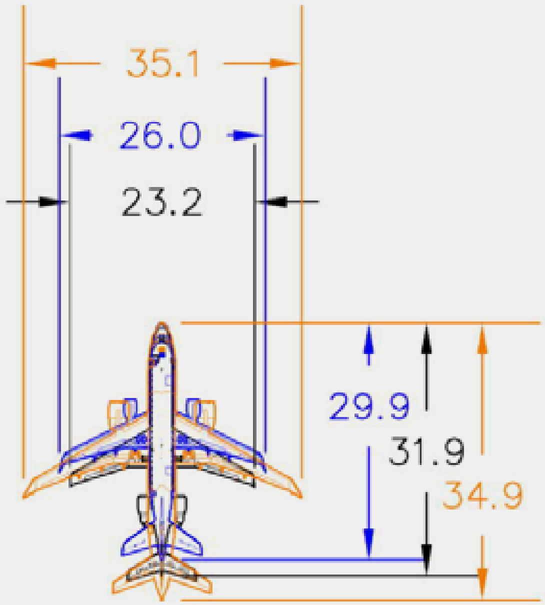
A321NEO vs 767-400ER



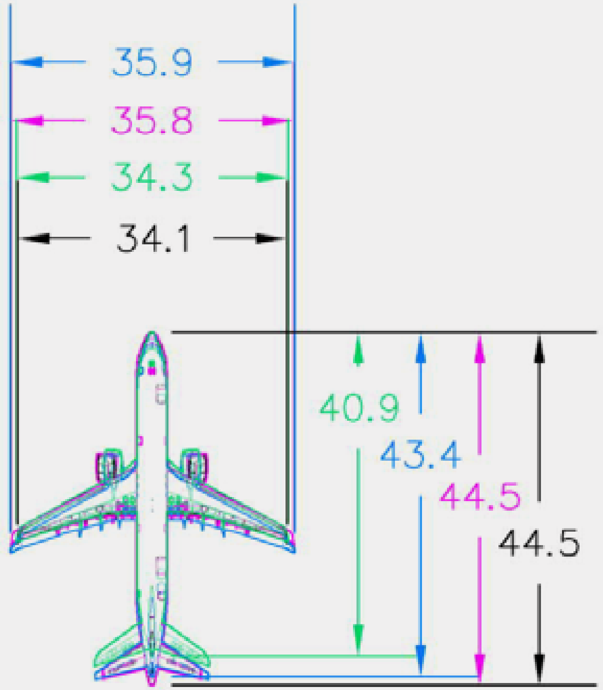
747-400ER vs 747-8 vs A380-800



717-200 vs A220-300



CRJ-700 vs E170-LR vs A220-100



A321-100 vs A321NEO vs 737-900 vs 737MAX10

FIGURE 39. PHYSICAL CHARACTERISTICS OF AIRLINERS CURRENTLY IN SERVICE

TABLE 6. CHARACTERISTICS OF PASSENGER COMMERCIAL AIRCRAFT

MANUFACTURER	Airbus	Airbus	Airbus	Boeing	COMAC	Embraer
TYPE	A220-300	A321XLR[2]	A350-1000	777-9[3,4,5]	C919ER[6]	E195-E2
ENTRY INTO SERVICE	2020	2024	2019	2025	2023	2019
WINGSPAN X LENGTH	35.1 m x 38.7 m (115 ft.x 126 ft.)	35.8 m x 44.5 m (117 ft. x 146 ft.)	64.8 m x 73.8 m (212 ft. x 242 ft.)	64.8 m x 76.7 m (213 ft. x 252 ft.)	35.8 m x 38.9 m (117 ft. x 128 ft.)	35.1 m x 41.5 m (115 ft. x 136 ft.)
ENGINES	2	2	2	2	2	2
PASSENGERS	120-150	180-244	369-480	349-426	158-192	120-146
MAXIMUM RANGE	3,350 NM (6,200 km)	4,700 NM (8,700 km)	8,700 NM (16,100 km)	7,285 NM (13,500 km)	3,011 NM (5,576 km)	2,600 NM (4,800 km)
MTOW	70.9 t	101 t	319 t	351.5 t	78.9 t	61.5 t
RUNWAY LENGTH REQUIREMENT[1]	2,743 m (9,000 ft.)	2,811 m (9,222 ft.)	2,600 m (8,500 ft.)	3,048 m (10,000 ft.)	2,125 m (6,972 ft.)	1,750 m (5,141 ft.)

Note:
This short-selection of airliners provides data on some of the most common critical design aircraft used for long-term planning purpose at large commercial airports.

1–Takeoff requirement assuming MTOW, ISA, Sea Level, Dry Runway.
2–The runway length requirement was computed based on the data released for the A321neo. The dimensions of the A321XLR are the same than those of the A321neo and A321LR it is derived from.
3–The runway length requirement was computed based on the data released for the 777-300ER based on Boeing's recommendations.
4–The 777-8 and -9 will have folding wingtips (FWT). When the FWT are unfolded (takeoff & landing), the wingspan will be 71.8 m (235 ft.).
5–A proposed lengthened version (777-10X) had a length of 80 m (263 ft.).
6–The range, MTOW, and runway length requirement is provided for the C919ER version. The C919 and its ER derivative have the same external dimensions.
.

MANUFACTURER	Airbus	Airbus	Airbus	Boeing	Boeing	Boeing
TYPE	A321P2F	A330-200F	A350F	737-800 BCF	747-8F	777-8F
ENTRY INTO SERVICE	2020	2010	2026	2018	2011	2028
WINGSPAN X LENGTH	35.8 m x 44.5 m (117 ft. x 146 ft.)	60.3 m x 58.8 m (198 ft. x 193 ft.)	64.8 m x 70.8 m (212 ft. x 231 ft.)	35.8 m x 39.5 m (117 ft. x 130 ft.)	68.4 m x 76.3 m (224 ft. x 250 ft.)	64.8 m x 70.9 m (212 ft. x 232 ft.) [folded]
ENGINES	2	2	2	2	4	2
PAYLOAD	27 t	61 t	111 t	21 t	140 t	112 t
CARGO VOLUME	207 m^3	469 m^3	695 m^3	185 m^3	853 m^3	780 m^3
MAX. RANGE	3,800 km	7,400 km	8, 704 km	4,760 km	8,130 km	8,170 km
MTOW	93.5 t	233 t	319 t	79 t	447 t	365 t
RUNWAY LENGTH REQUIREMENT[1]	2,500 m (8,200 ft.)	2,770 m (9,090 ft.)	N/A	1,980 m (6,500 ft.)	3,050 m (10,000 ft.)	N/A

1–Takeoff requirement assuming MTOW, ISA, Sea Level, Dry Runway.

TABLE 7. CHARACTERISTICS OF MEDIUM- AND LARGE-SIZE FREIGHTERS

MANUFACTURER	Aérospatiale/BAC	Aerion	Spike	Boom	Exosonic
TYPE	Concorde	AS2	S-512 Diplomat	Overture	Currently unnamed
MARKET SEGMENT	Commercial aviation	Business aviation	Business aviation	Commercial aviation	Commercial aviation
STATUS	Retired	Project terminated	Under development	Under development	Under development
ENTRY INTO SERVICE	1976	Cancelled	TBD	2029	TBD
WINGSPAN X LENGTH	25.6 m x 61.7 m	23 m x 52 m	17.7 m x 37 m	18 m x 61 m	–
CRUISE SPEED*	Mach 2.04	Mach 1.4	Mach 1.6	Mach 1.7	Mach 1.8
ENGINES	4	3	2	4	4
PASSENGERS	92-128	8-11	12-18	64-80	70
MAX. RANGE W/ SUPERSONIC CRUISE	3,900 NM (7,223 km)	4,200 NM (7,780 km)	6,200 NM (11,482 km)	4,250 NM (7,870 km)	5,000 NM (9,260 km)
RUNWAY LENGTH REQUIREMENT**	3,600 m (11,800 ft.)	2,286 m (7,500 ft.)	1,828 m (6,000 ft.)	3,048 m (10,000 ft.)	–
LOW-BOOM TECHNOLOGY	No	Yes	Yes	No	Yes
AIRPORT COMPATIBILITY FEATURES	None	Non-afterburning engines	"Quiet supersonic flight technology"	Non-afterburning engines	"Sonic boom shaping technology"
UNIT COST (USD2024)	$190 Million	$140 Million	–	$200 Million	–
CLIENTS	AFR, BAW	Flexjet	–	AAL, JAL, UAL	–

*Assuming a cruising altitude of 60,000 ft.
**Takeoff requirement assuming MTOW, ISA, Sea Level.

TABLE 8. COMPARISON BETWEEN CONCORDE AND PROPOSED SUPERSONIC AIRCRAFT

TABLE 9. CHARACTERISTICS OF PROPOSED HYPERSONIC AIRCRAFT

MANUFACTURER/R&D	Aérospatiale	Boeing	Reaction Engines	SpaceX
TYPE	Avion à Grande Vitesse	Currently Unnamed	Skylon	Starship
STATUS	Late 1980s concept	2020 concept	Under development	Under development
WINGSPAN X LENGTH	–	“Smaller than a 737”	26.8 m x 83.1 m (88.0 ft. x 273 ft.)	9 m x 118 m* (30 ft. x 387 ft.)
CRUISE SPEED	Mach 5	Mach 5	Mach 5.5	Mach 20**
CRUISE ALTITUDE	100,000 ft.	–	Suborbital	Suborbital
ENGINES	4 or 6 methane ramjets	–	2 ramjets	37+6 rocket engines*
PASSENGERS	150	<100?	30	>100
MAX. RANGE	13,900 km	–	–	–

*Diameter x height with booster. This is a Two-Stage-To-Orbit, vertical launch/vertical landing rocket. Lower stage has 36 Raptor rocket engines. Starship is equipped with 6 Raptor rocket engines. **During atmospheric flight.

MANUFAC-TURER/R&D	Destinus	Destinus	Hermeus	Venus
TYPE	S	L	Halcyon	Stargazer
STATUS	Under development	Under development	Under development	Under development
WINGSPAN X LENGTH	18 m x 40 m	–	–	–
CRUISE SPEED	Mach 5	Mach 6	Mach 5	Mach 9
CRUISE ALTITUDE	110,000 ft.	–	90,000 ft.	170,000 ft.
ENGINES	Hydrogen turbojet and ramjet engines	Hydrogen turbojet and ramjet engines	4 combined cycle engines	Rotating detonation rocket engines
PASSENGERS	25	400	20	12
MAX. RANGE	10,000 km	22,000 km	7,400 km	>8,050 km

SPACECRAFT OPERATOR	Northrop Grumman IS	The Spaceship Company	SNC Space Systems	Stratolaunch	Blue Origin	SpaceX
SPACECRAFT MODEL	L-1011 Stargazer/ Pegasus XL	WhiteKnight/ Spaceship Two	Dream Chaser	Model 351 “Roc”/ Talon-A	New Shephard	Starship
STATUS	In service	In service	Under development*	Under testing	In service	Under development
MISSION	Small satellites	Suborbital flights	ISS resupply (manned or cargo)	Hypersonic R&D	Suborbital flights	Heavy orbital multi-missions
DIMENSIONS	See L-1011	43 m x 24 m (141 ft. x 79 ft.)	7 m x 9 m (23 ft. x 30 ft.)	73 m x 117 m (240 ft. x 384 ft.)	7 m x 18 m (23 ft. x 56 ft.)	9 m x 118 m (30 ft. x 387 ft.)
LAUNCH	Air launch-to-orbit	Under WK2	ULA Vulcan	Under the Roc	Vertical	TSTO
REENTRY	N/A	Glided reentry	Glided reentry	Glided flight	Vertical	

*The vehicle should be launched for the first time in 2025.

TABLE 10. CHARACTERISTICS OF SPACECRAFT AND CARRIER VEHICLES

APPENDIX H
CARGO VOLUME VS PAYLOAD OF COMMERCIAL FREIGHTERS

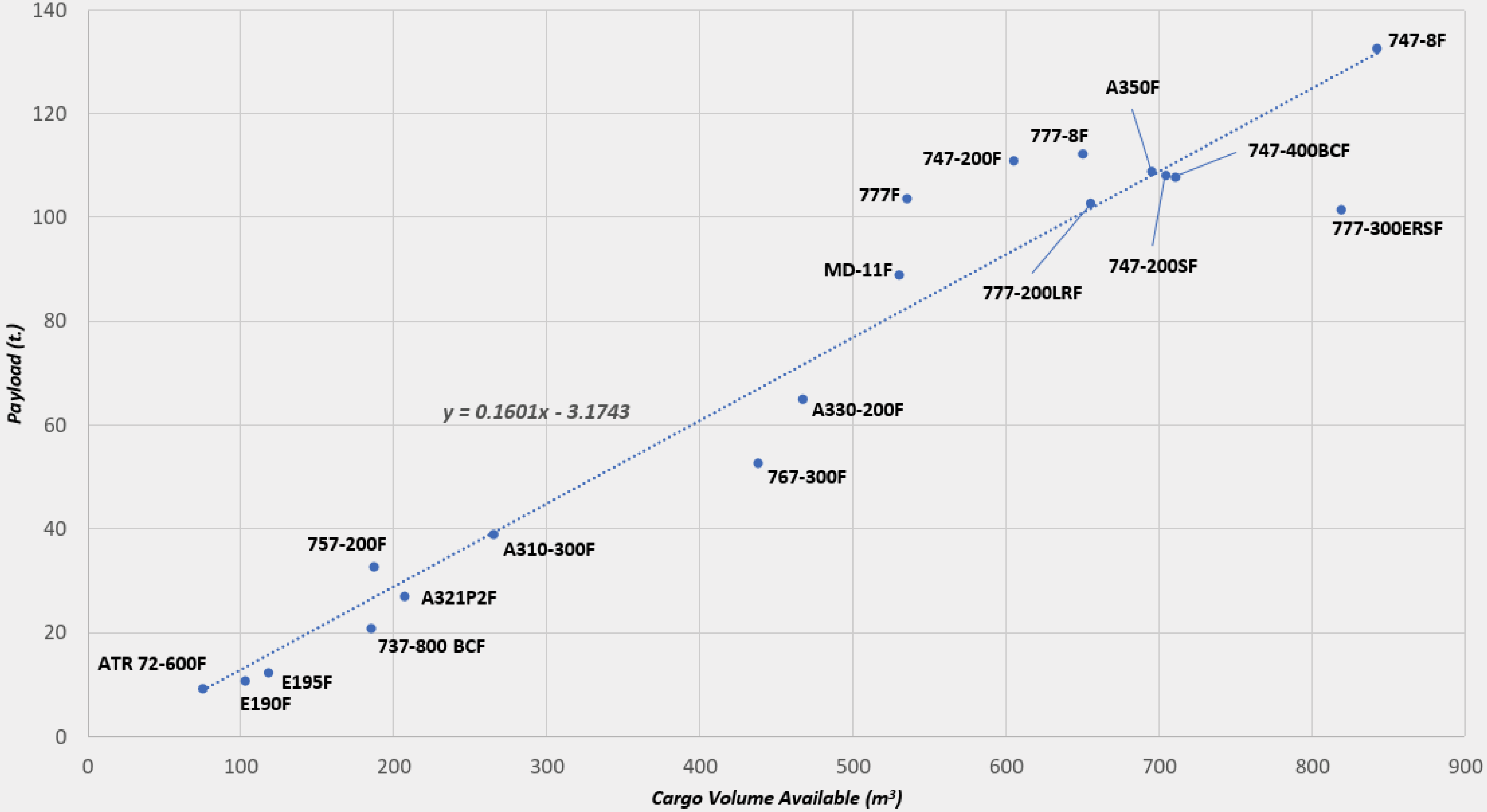


FIGURE 40. CARGO VOLUME VS PAYLOAD OF COMMERCIAL FREIGHT

Source: Le Bris & Nguyen (2024)

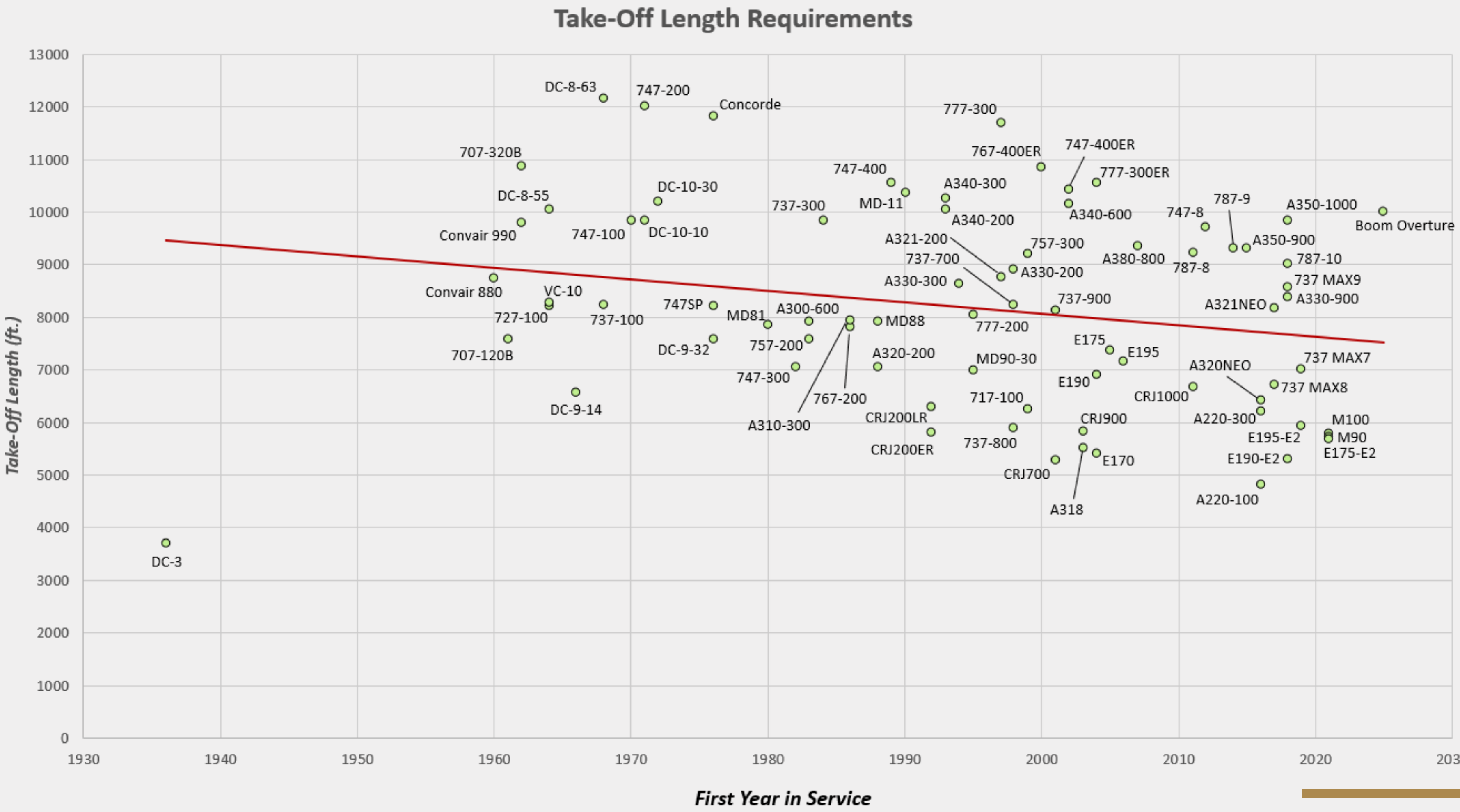


FIGURE 41. LONG-TERM TRENDS ON RUNWAY LENGTH REQUIREMENTS OF TRANSPORT JET AIRCRAFT FOR AIRPORT PLANNING

Source: Le Bris & Nguyen (2021)

TABLE 11. INNOVATIVE AIRCRAFT FEATURES AND THEIR IMPACT ON AIRPORT COMPATIBILITY

DESIGN FEATURE	DEPICTION	COMMENTS ON AIRPORT COMPATIBILITY	EXAMPLE(S)
Propfan (open rotor)		Less emissions but noisier than comparable turbojets.	Antonov An-70 Boeing 7J7
Tail-mounted engines		Less noise to the ground when airborne than comparable turbojets. Lower hazards for ground handling. Low risk of FOD ingestion. Jet blast hazard at higher height.	Airbus A30X CleanSky HSBJ
High-aspect ratio wings		Wider wingspan might warrant folding wingtip technologies for airport compatibility purpose.	Hurel-Dubois Nasa TTBW NASA/Boeing X-66A
Blended wing body		Aircraft evacuation concepts to be developed. Doors are farther from lead-in line (jetbridge compatibility). Larger wheel span for ensuring lateral stability (taxiway compatibility). Larger high-capacity flying wings (if any) will challenge airport compatibility.	Airbus Maveric Airbus ZEROe Boeing BWB JetZero Z-5

DESIGN FEATURE	DEPICTION	COMMENTS ON AIRPORT COMPATIBILITY	EXAM-PLE(S)
Boxed wings		Smaller wingspan than comparable turbojets. Opportunity for engines mounted on upper wing. Potential issues with accessing the fuselage (depending on configuration).	NASA/Lockheed Martin
Folding wingtips		Significantly increase compatibility with existing airport infrastructure. Requires airport-friendly CONOPS (see BACG2).	Boeing 777-8/-9/-8F
Aeroelastic hinged wingtips		Opportunity to increase wingspan during cruise and preserve airport compatibility with folding wingtip technology at the hinge.	Airbus AlbatrossONE
Electric and hybrid propulsion systems		Fully electric aircraft are zero-emission at the tailpipe. Requires fast chargers at the gate. Requires airports to become more power resilient.	Archer Midnight Heart ES-30 Volocopter Volocity
Hydrogen gas turbines		Significant reduction of carbon emissions at the tailpipe. Requires hydrogen supply chain able to provide large quantities. Airport design criteria based on Jet A-related hazards to be reassessed.	Airbus ZEROe Embraer Energia

BACKGROUND

This section presents and analyzes four notional future aircraft concepts adopting next generation technologies discussed in Chapter 6: Airport Compatibility: Accommodating the Next Generation of Aircraft Technologies. These notional aircraft concepts were developed for The Future of Airports: A Vision of 2040 and 2070 with the purpose of assessing the potential impact of new aircraft configurations and innovative aircraft technologies at airports. The combinations of innovative features selected for these notional aircraft concepts do not advocate for or against other combinations or engineering solutions. These notional aircraft concepts do not depict any specific product but they are rather inspired by ongoing efforts made by original equipment manufacturers and the aerospace research community to deliver actionable innovations to make commercial aviation more sustainable and efficient.

Aircraft/airport compatibility is an important driver in the design of transport aircraft and, ultimately, in their commercial and operational success. The physical characteristics of aircraft have to be consistent with the airfield facilities in order to maintain the collision and excursion risks below certain levels of safety. Airfield design standards provide criteria for meeting this goal. When standards are not met, aeronautical studies can be developed to assess if the conditions achieve an equivalent level of safety.

Aircraft/airport compatibility is not limited to geometry issues. New aircraft shall be operations-friendly on the ground and in the air, and address airspace operations, radionavigation interference risks, aviation pavements, airport terminal facilities, and noise and emissions aspects as well. This appendix does not investigate all of these domains but rather presents selected findings on gate and taxiway compatibility.

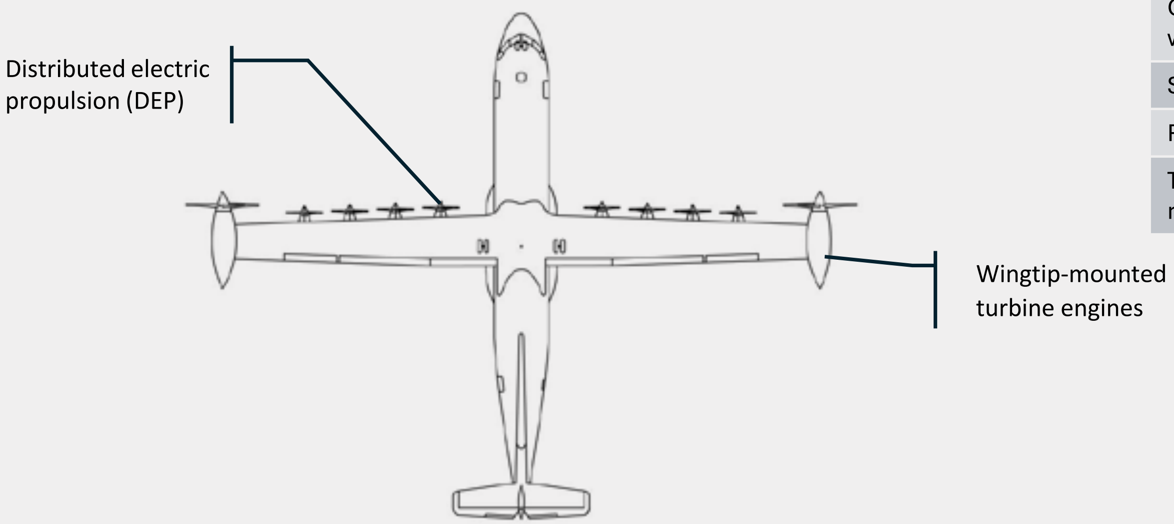
NAC REGIO: INNOVATING IN PROPULSION SYSTEMS FOR THE SHORT-HAUL REGIONAL MARKET IN 2030

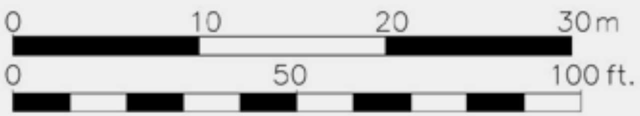
DESCRIPTION:

The notional future regional aircraft concept or NAC Regio is comparable to the ATR 72-600 and would fly regional routes currently operated with small turboprop or jet aircraft (Figure 42). Assuming the same wing area than the ATR 72, it features a larger 36-meter-wide wingspan (ICAO Letter of Code C) providing for a distributed electric propulsion (DEP) system made of four electric motors on each wing and wingtip-mounted turbine engines driving larger propellers and generating electricity (series hybrid propulsion system).

Most of the enabling technologies for such an aircraft have been demonstrated or are under development. Hybrid-electric and fully-electric regional aircraft could emerge first among the commercial aircraft adopting breakthrough innovations, with both legacy manufacturers and startups developing products that may perform their first flight over the next five years. Therefore, it is estimated that a full-scale commercial aircraft prototype based on this concept could fly at the 2030 horizon.

NAC Regio: Hybrid-Electric Regional Aircraft





	NAC Aircraft	Comparable Aircraft (Baseline)
Model	NAC Regio	ATR 72-600
Length	27.2 m	27.2 m
Wingspan	36.0 m *Code C/FAA ADG III*	27.1 m *Code C/FAA ADG III*
Outer main gear wheel span	4.65 m *FAA TDG 2A*	12.8 m *FAA TDG 6*
Seats	72	72
Range	Similar to Baseline	825 NM
Technology readiness	2030+	Today

Related R&D:
Daher/Airbus EcoPulse
Leonardo HERA
NASA X-57 Maxwell
NASA LEAPTech

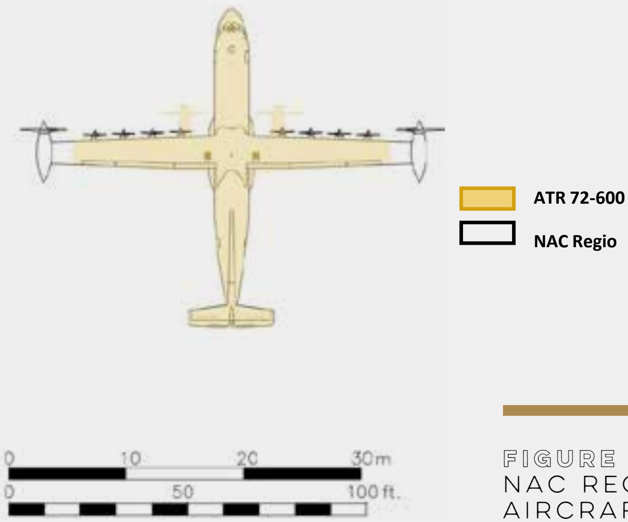


FIGURE 42.
NAC REGIO AIRCRAFT CHARACTERISTICS

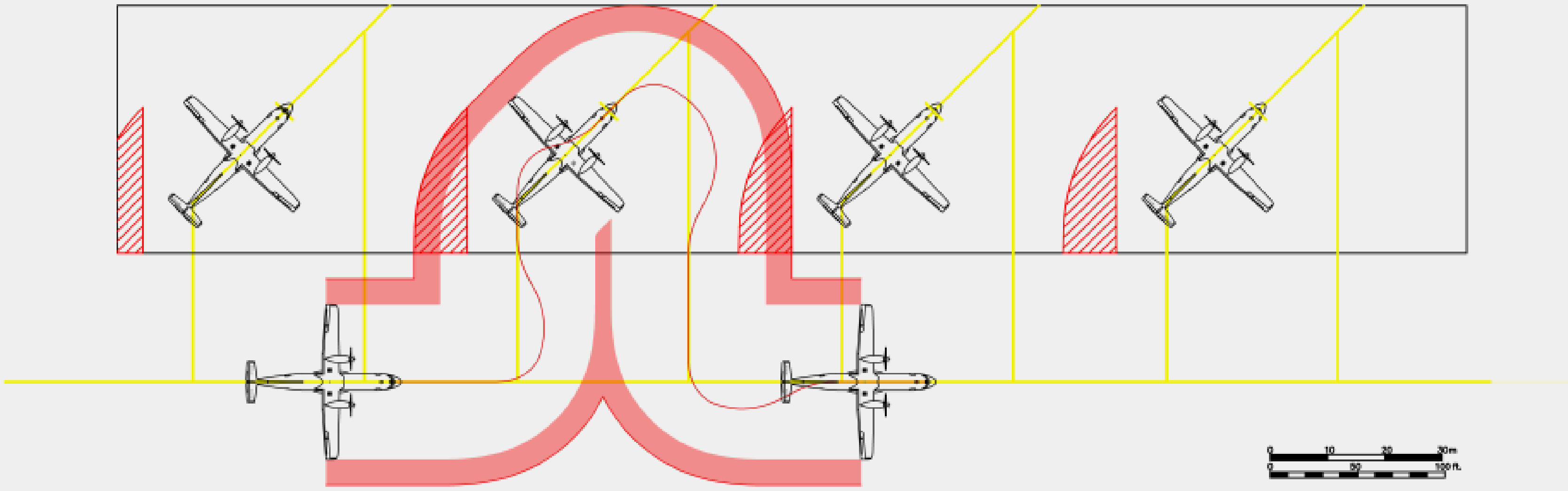


FIGURE 43.
BASELINE REGIONAL APRON WITH SELF-MANEUVERING NOSE-IN PARKING FOR ATR 72-600

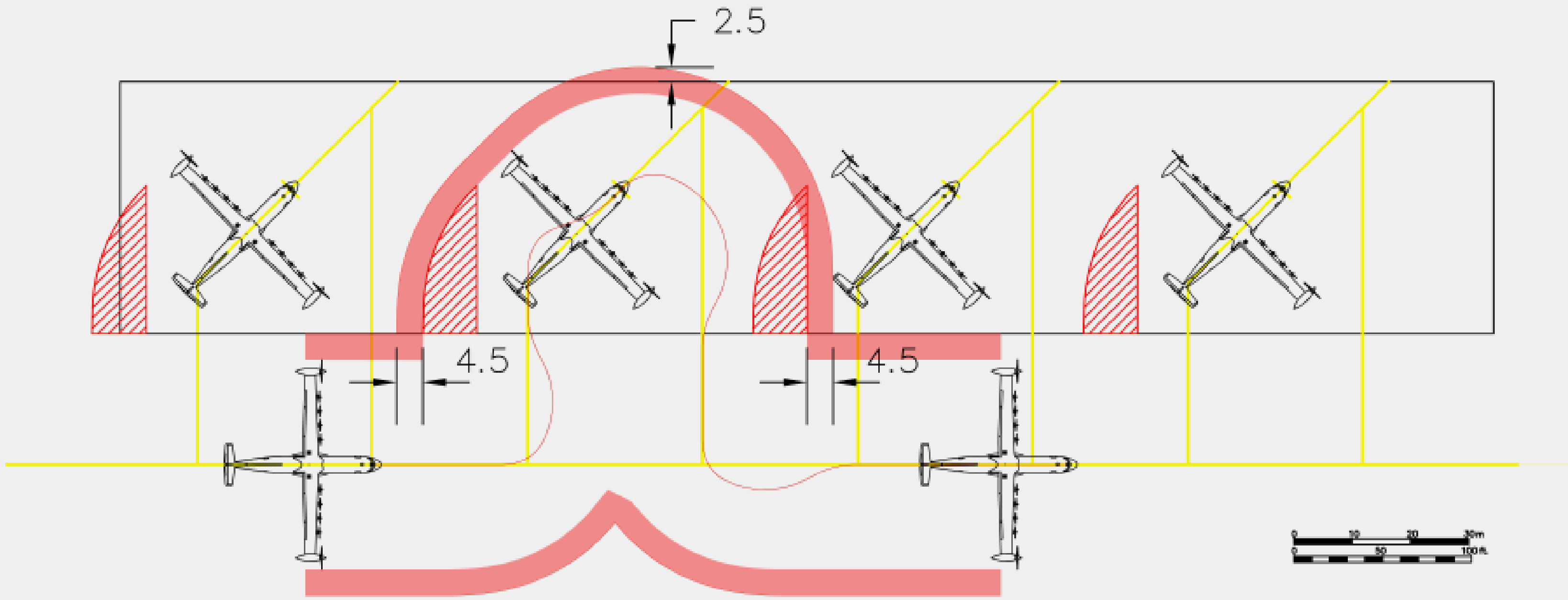


FIGURE 44.
NAC REGIO MANEUVERING ON THE BASELINE REGIONAL APRON

AIRPORT COMPATIBILITY:

Figure 43 depicts a typical self-maneuvering 45°-angled nose-in parking layout for small piston-engine and turboprop commercial aircraft up to the ATR 72-600. These stands cannot be operated independently, as no aircraft can taxi-in or -out when another aircraft is moving on an adjacent stand.

The introduction of the NAC Regio at this airport (Figure 44) would require specific provisions in terms of operating procedures as well as a potential restriping of the no-parking areas between the stands. Indeed, the positioning of propellers on the wing extremities creates a new hazard that is no longer contained within the wingspan like with today's propeller aircraft. This means that the notion of wingspan needs to be inclusive of the outer propeller rotation discs. Also, such particularity should be brought to the attention of the operating staff–especially agents involved with ground handling operations–as a major occupational hazard that is absent from existing aircraft configurations. Propeller hazard areas should be marked on the ground, including at airports that have not adopted this practice.

Also, the wider wingspan (inclusive of the outer propeller) defines a larger area where no personnel nor equipment should be parked when the aircraft is in movement. Consequently, the no-parking areas should be adapted to the characteristics of the NAC Regio and re-stripped accordingly. The object free area between the propeller discs and nearby obstacles, roads, and pedestrian paths should be assessed for this new aircraft types (Figure 45).

A reconfiguration of the apron may be preferrable in certain cases (Figure 46). The adoption of a parallel parking layout might be warranted to meet all safety and operational criteria. However, the various impacts of such change need to be considered in the decision-making process. For instance, unless a taxilane can be created on the other side of the ramp, the new layout will require pushback for taxiing-out, which means that tow-tractors should be available for supporting push-out operations and minimize the turnaround time. On the other hand, self-maneuvering angled stands are expansive, and a parallel nose-in/push-out configuration is usually more capacitive. Also, it promotes deeper stands which can be compatible with bigger aircraft (Embraer E175-E2 depicted).

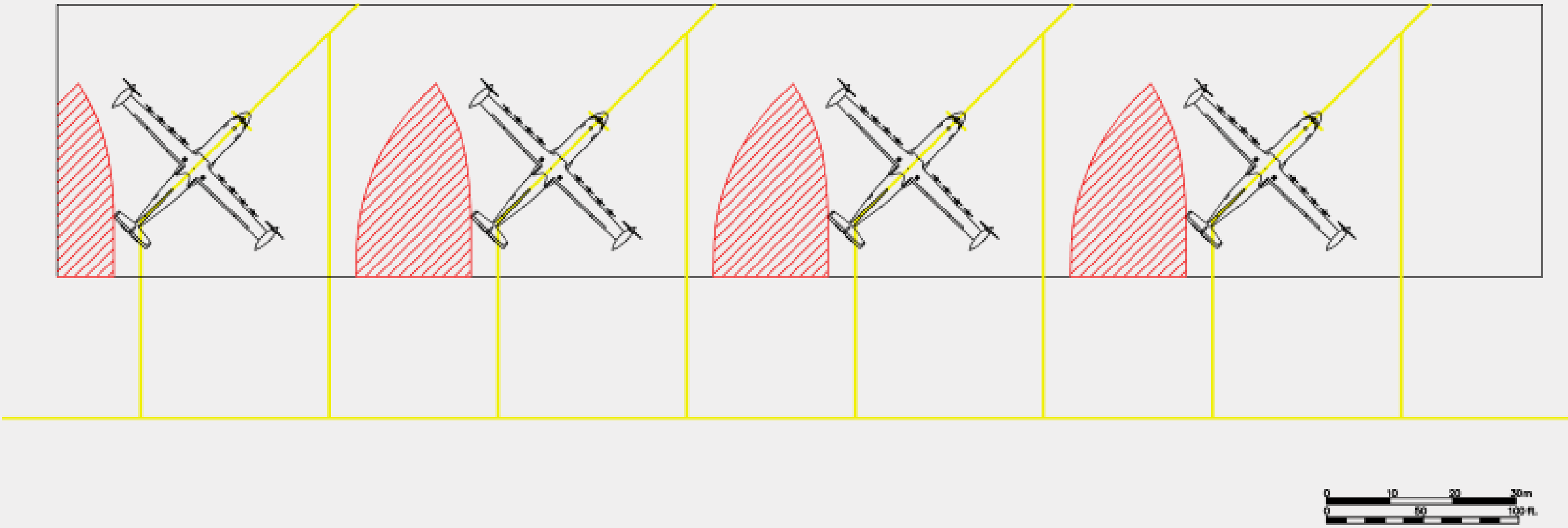
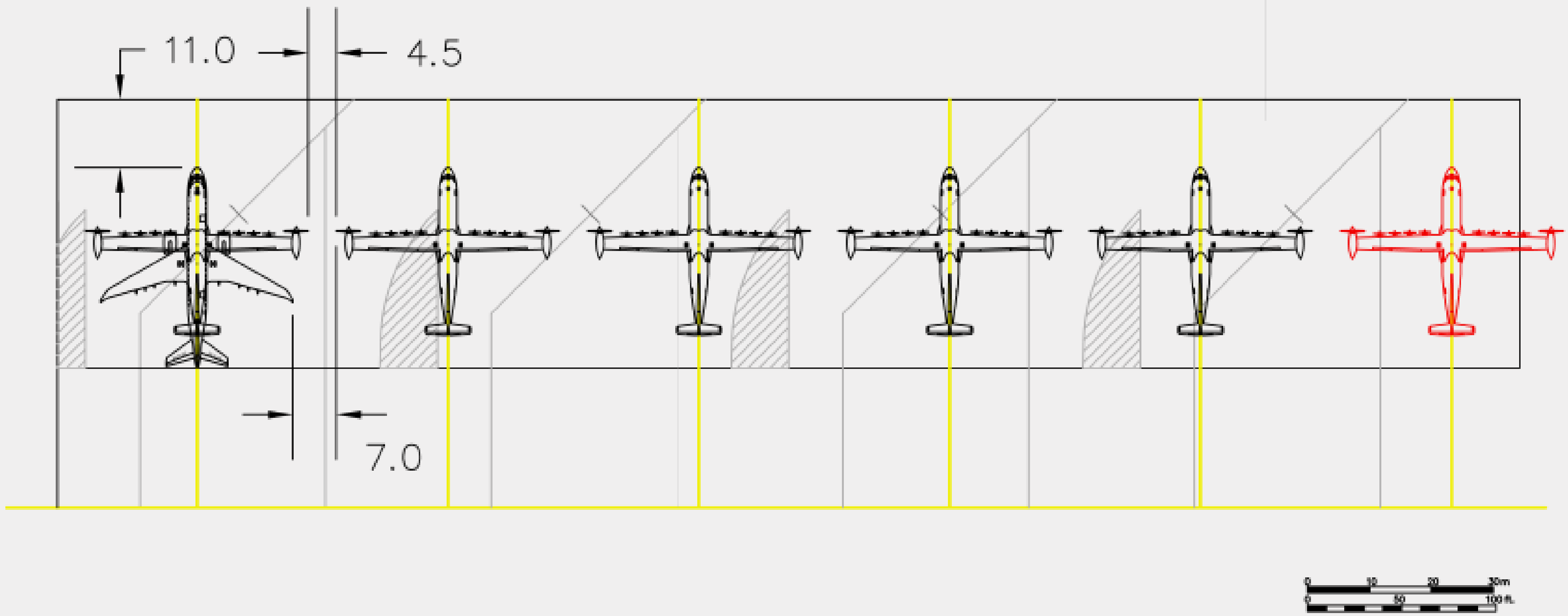


FIGURE 45. RESTRIP-ING OF THE REGIONAL APRON FOR THE NAC REGIO

FIGURE 46. REDEVELOP-MENT OF THE REGIONAL APRON FOR NAC REGIO PARALLEL PARKING



NAC1: INTRODUCING BREAHTROUGH INNOVATION FOR THE NEXT GENERATION NARROWBODY AIRCRAFT IN 2035

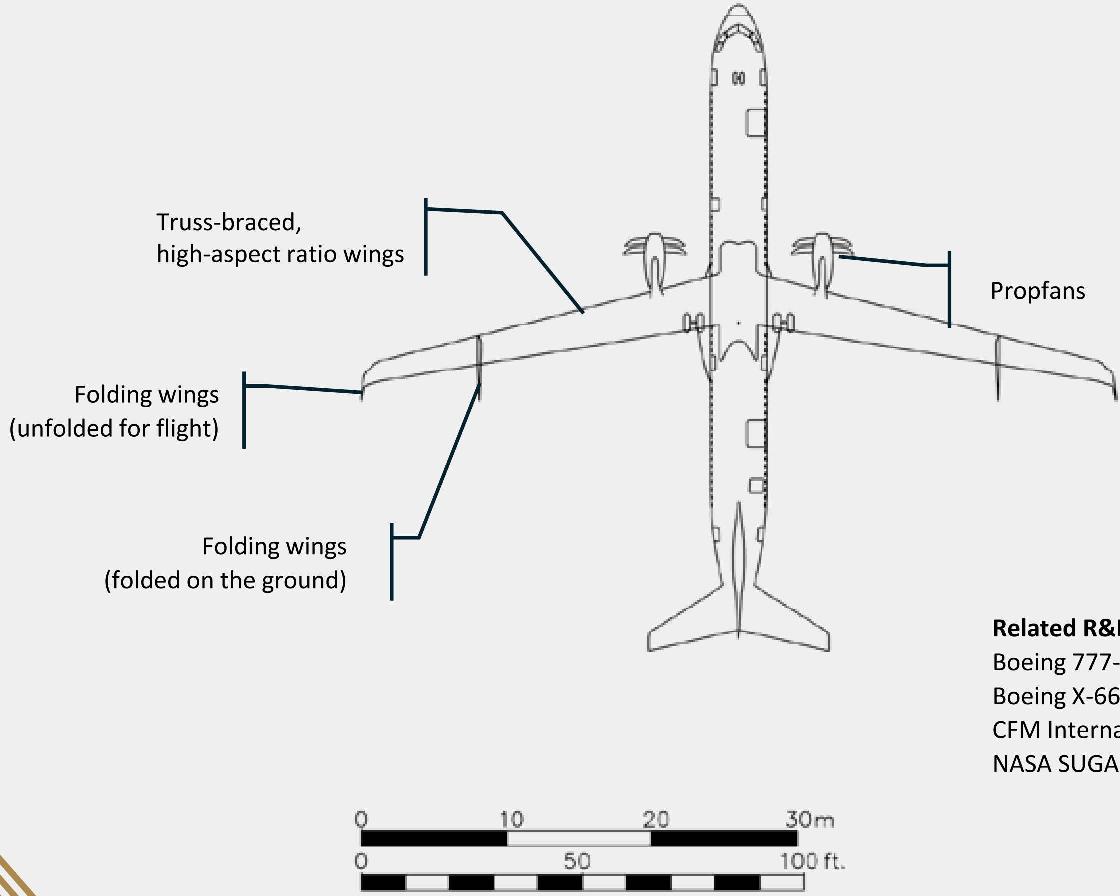
DESCRIPTION:

The NAC1 aircraft is a mainline jet aircraft comparable to the Airbus A321neo or Boeing 737 MAX 10. This notional aircraft is an example of what the next generation of narrowbody airliners could be. It features a high wing to provide sufficient ground clearance to large underwing engines. Its truss-braced, high-aspect ratio wing is 52-meter-wide in flight (Code D). With such wingspan, as determined in the subsequent gate assessment analysis, the NAC1 cannot be accommodated at gates designed for existing narrowbody aircraft (Code C) without significantly reducing capacity (Table 12). This is why folding wings should be to incorporate on future wider-wingspan aircraft. Folding wings would enable the NAC1 to become a Code C aircraft (36m wingspan) after vacating the runway.

The NAC1 aircraft is depicted in two versions optimized for different cruise speeds. The NAC1P (Propfan) cruises at Mach 0.70. It is powered by two propfan (open rotor) gas turbines (Figure 47). The NAC1T (Turbofan) can cruise faster at Mach 0.80. It has two ultra-high bypass ratio jet engines (Figure 48). A technology demonstrator for high-aspect ratio, truss-braced wings will fly in 2028. Open rotor and ultra-high bypass ratio engines are under development. Folding wingtip technologies for commercial aircraft are now flight proven. Therefore, it is estimated that a combination of these innovative features will be flight-ready by 2035.

This date acknowledges the interest of the industry for these technologies, publicly-backed research initiatives for advancing them, as well as statements made by aircraft manufacturers including Airbus and Boeing regarding the timeline for a potential decision on their next generation products. This does not necessarily mean that an entry into service will happen in 2035, but rather that the industry should be able to fly a full-scale commercial demonstrator or prototype by this date as long as decisions are made by OEMs before 2030 regarding the adoption of breakthrough technologies for their next programs.

NAC1P (Propfans): Next Gen Narrowbody Aircraft



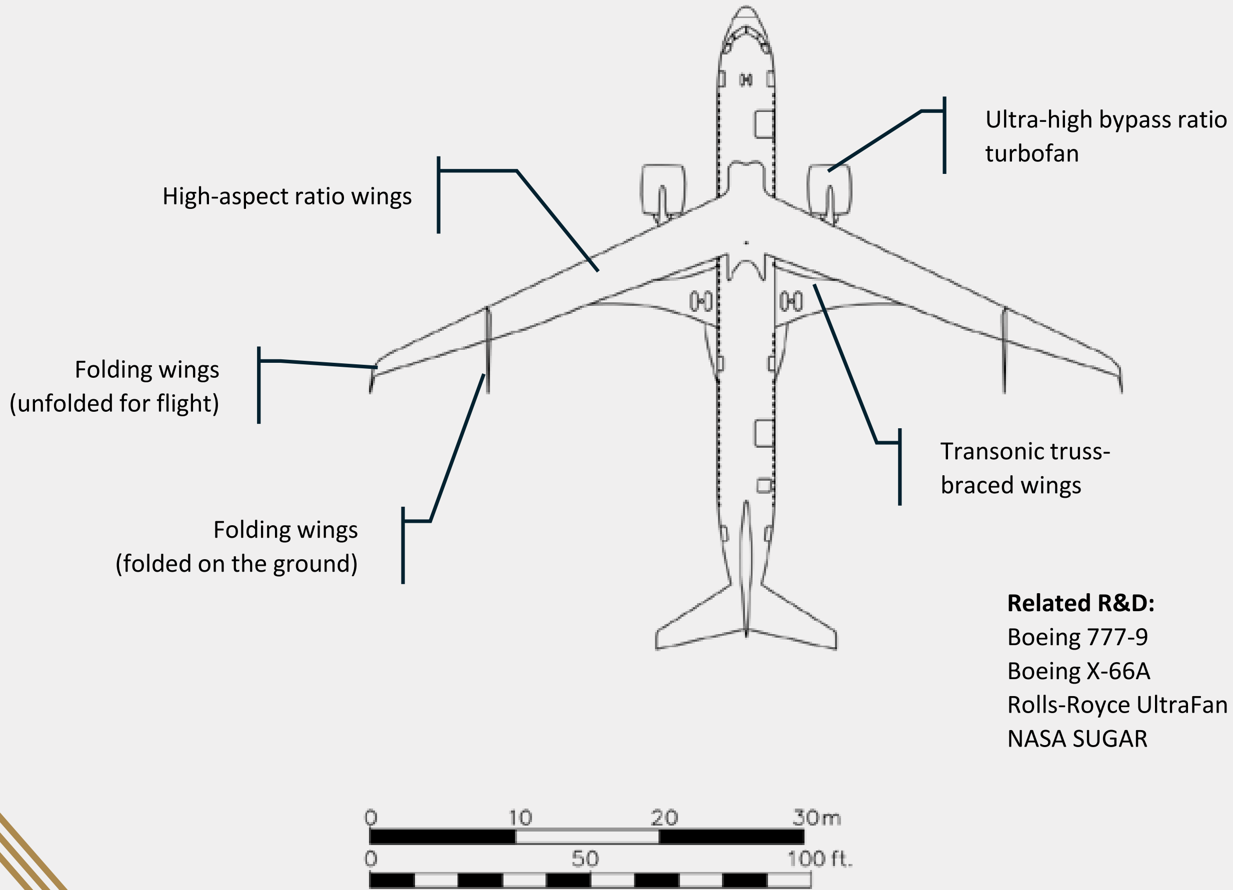
Related R&D:
Boeing 777-9
Boeing X-66A
CFM International Rise
NASA SUGAR

	NAC Aircraft	Comparable Aircraft (Baseline)
Model	NAC1P	Airbus A321neo
Length	44.5 m	44.5 m
Wingspan (wings folded)	36.0 m *Code C/FAA ADG III*	N/A
Wingspan (wings unfolded)	52.0 m *Code D/FAA ADG IV*	35.8 m *Code C/FAA ADG III*
Outer main gear wheel span	6.22 m *FAA TDG 3*	8.98 m *FAA TDG 3*
Cruise speed:	Mach .7	Mach .78-.82
Seats	200-240	206-244
Range	Similar to Baseline	5,625-6,473 NM
Technology readiness	2035	Today

FIGURE 47. NAC1P AIRCRAFT CHARACTERISTICS

NAC1T (Turbofans): Next Gen Narrowbody Aircraft

	NAC Aircraft	Comparable Aircraft (Baseline)
Model	NAC1T	Airbus A321neo
Length	44.5 m	44.5 m
Wingspan (wings folded)	36.0 m *Code C/FAA ADG III*	N/A
Wingspan (wings unfolded)	52.0 m *Code D/FAA ADG IV*	35.8 m *Code C/FAA ADG III*
Outer main gear wheel span	6.22 m *FAA TDG 3*	8.98 m *FAA TDG 3*
Cruise speed:	Mach .8	Mach .78-.82
Seats	200-240	206-244
Range	Similar to Baseline	5,625-6,473 NM
Technology readiness	2035	Today



Related R&D:
Boeing 777-9
Boeing X-66A
Rolls-Royce UltraFan
NASA SUGAR

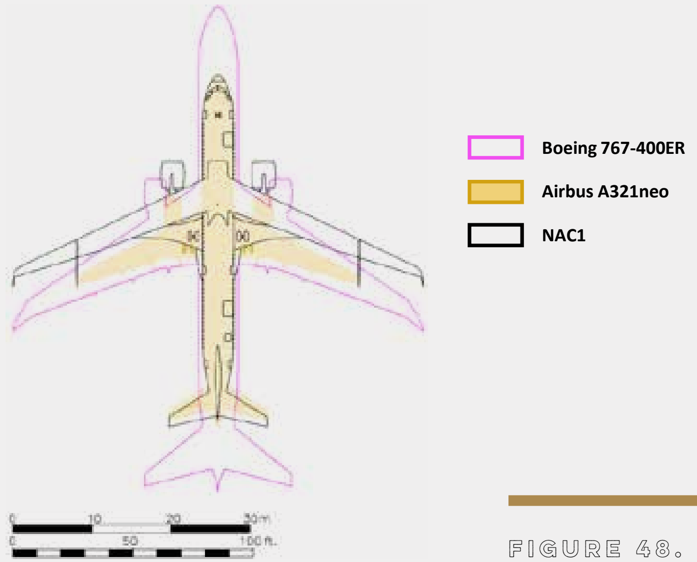
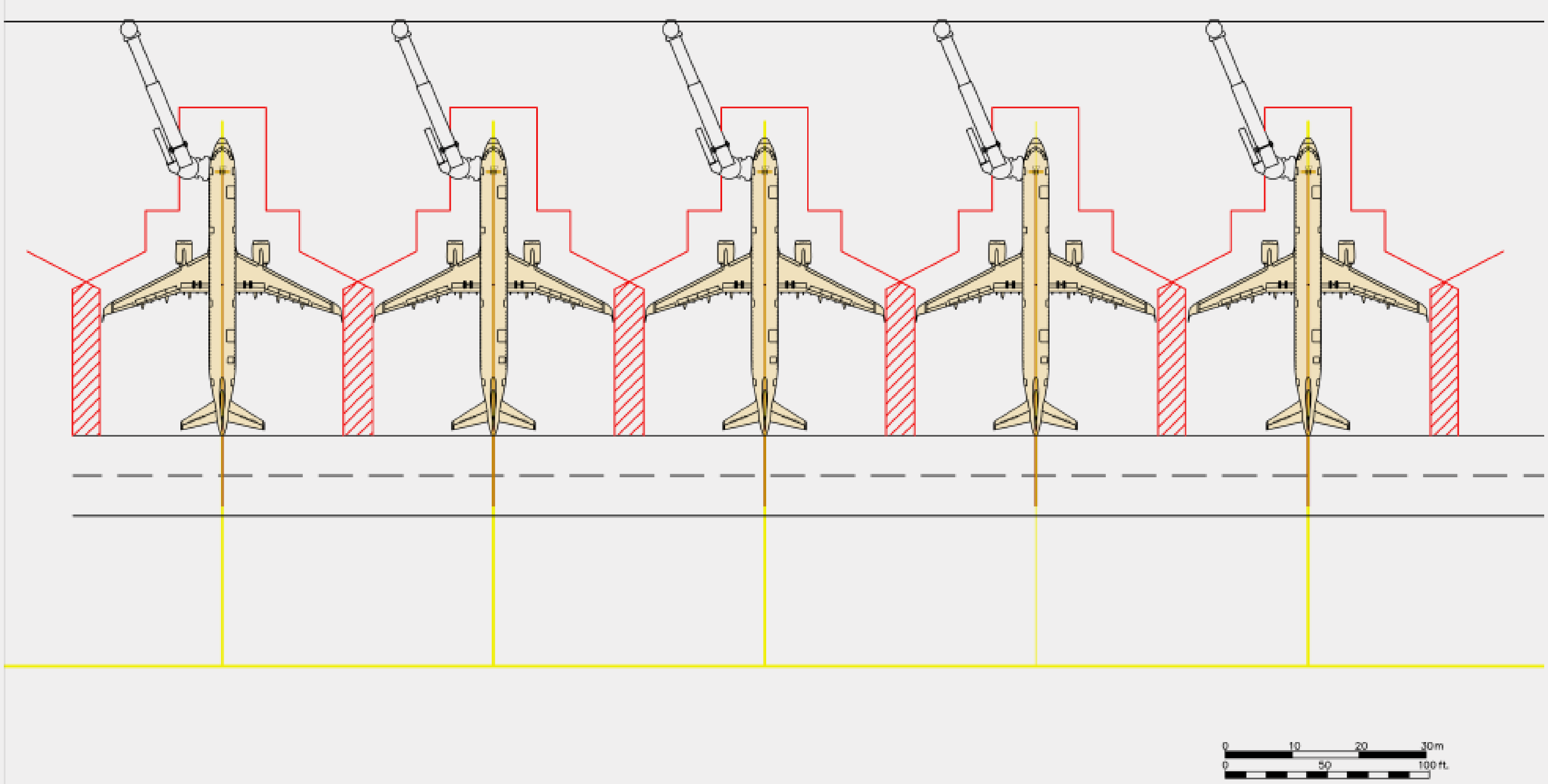


FIGURE 48. NAC1T AIRCRAFT CHARACTERISTICS

FIGURE 49.
BASELINE CODE C APRON WITH A321NEO



AIRPORT COMPATIBILITY:

Figure 8 shows several existing Code C aircraft (A321neo) parked on nose-in/push-out parallel stands. All aircraft are gated with passenger boarding bridges optimized for this configuration and airliners. The replacement of current narrowbody aircraft by airliners with NAC1-type wings without folding wing technology poses an immediate capacity issue with the impossibility to park NAC1 side by side using existing lead-in lines (Figure 50). Any stand surrounded by two NAC1 aircraft at the same time is unavailable to other mainline aircraft. Only small general aviation and commuter aircraft may be parked (Eviation Alice depicted) as no more than 29 m are available for the plane's wingspan and the passing margins. Alternatively, regional jets may be parked on gates surrounded by a parked NAC1 on one side and a Code C aircraft on the other side (Figure 51).

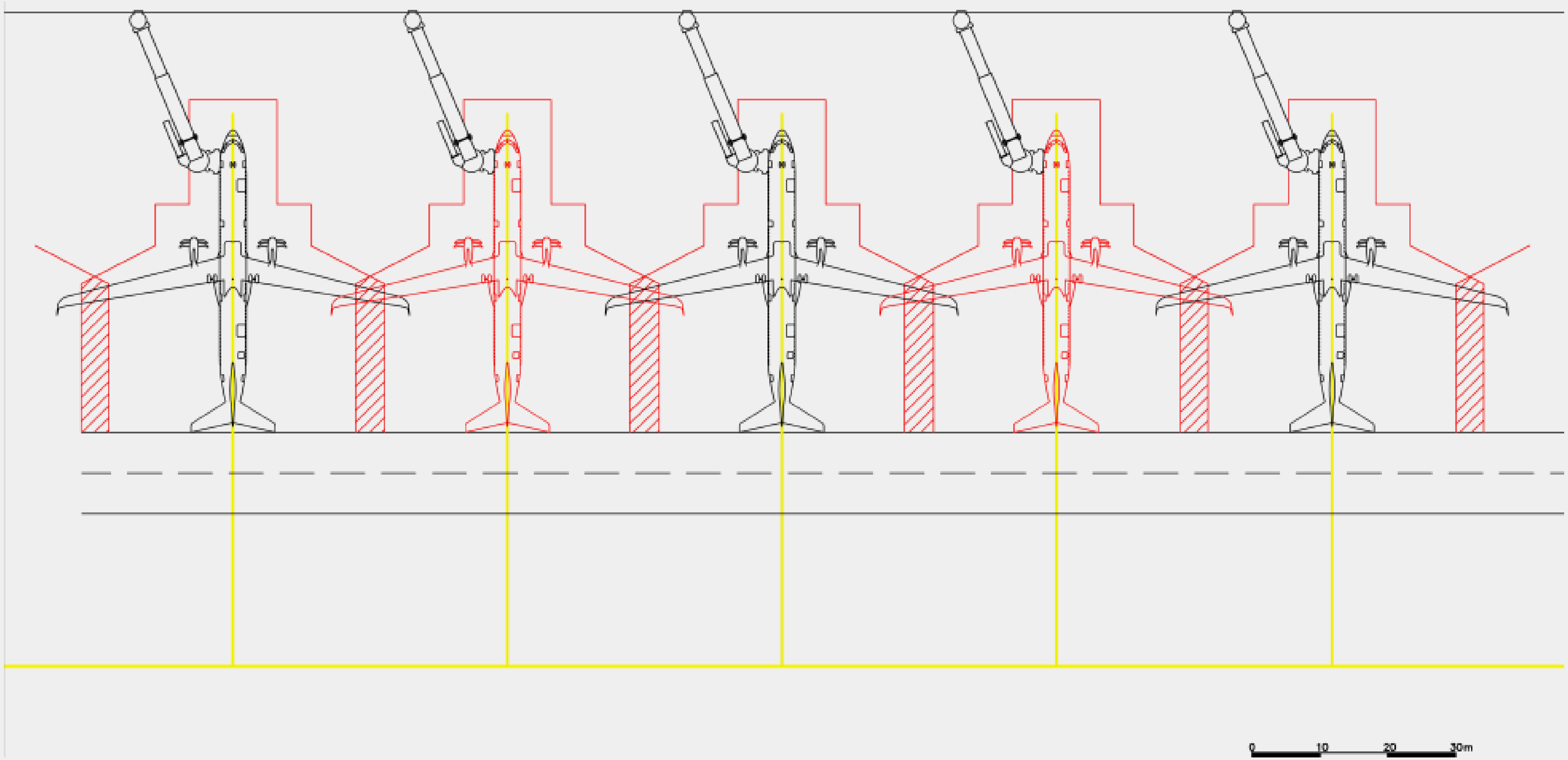
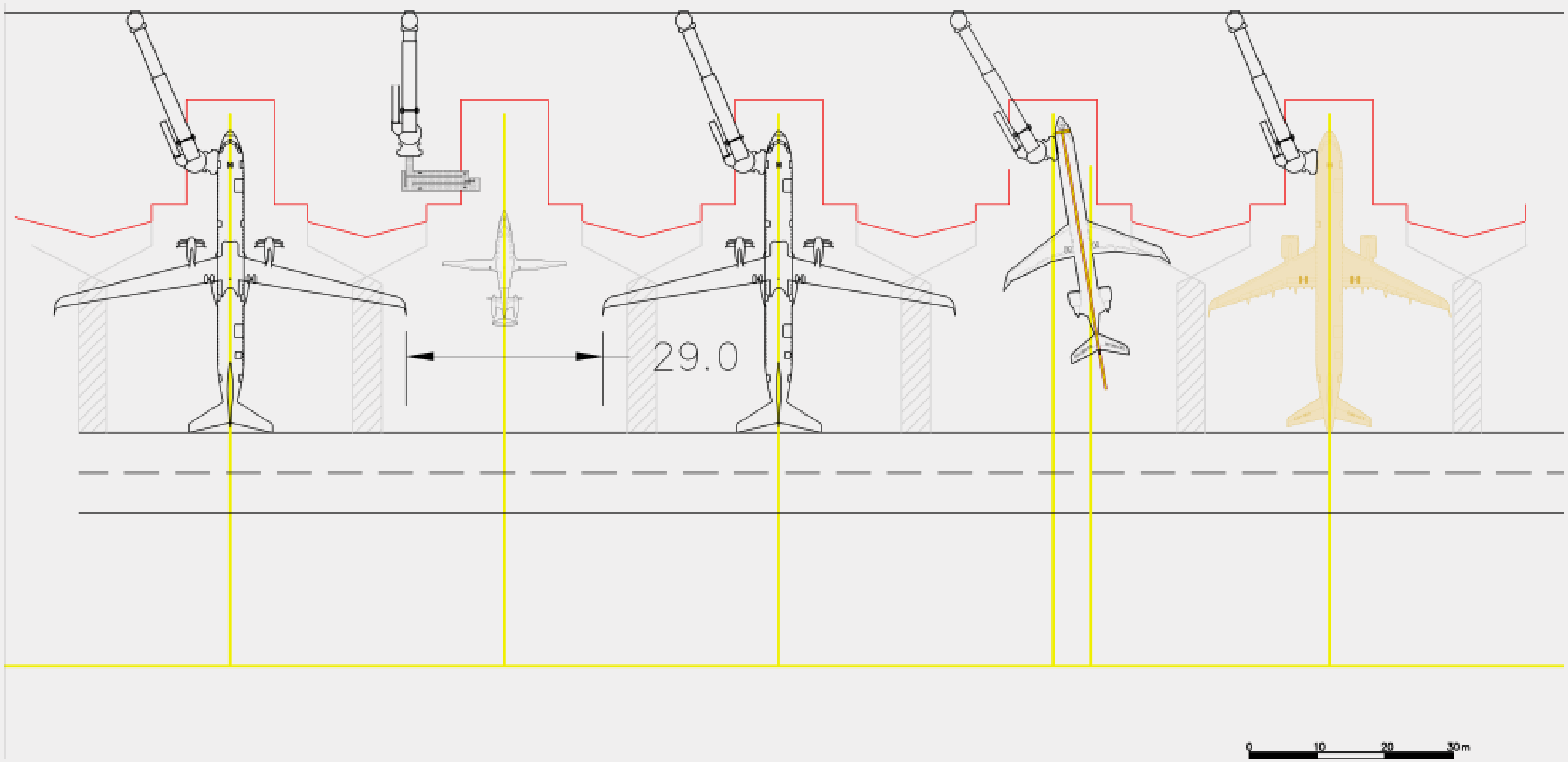


FIGURE 50. BASELINE CODE C APRON WITH NAC1P WITHOUT FOLDING WINGS

Adapting the parking layout for NAC1 without folding wings is costly, impactful, and goes beyond a simple restriping. It may warrant a combination of bridge replacement, gate relocation, and fuel pit relocation (Figure 52). Aprons and passenger terminals might need to be significantly expanded (Table 12). Other airfield compatibility issues could arise especially at regional airports designed for Code C aircraft specifically (e.g., taxiway-runway, taxiway-taxiway, and taxiway-obstacle separations).

Equipping fuel-efficient airliners with high-aspect ratio wings with folding wing technology is crucial to ensure their seamless introduction across aviation systems. Folding wings should allow an aircraft like the Code D NAC1 to fold back to a Code C wingspan after vacating the runway. This enables its integration into existing aircraft ramp systems (Figure 53). As the longitudinal position of the wings along the fuselage is slightly different on both the T and P versions of the NAC1 aircraft, fuel pits may have to be relocated.

FIGURE 51. BASELINE CODE C APRON WITH UNFOLDED NAC1P AND SMALLER AIRCRAFT



Jetbridge operators should be aware of the close proximity of the engines with the first aircraft door, especially on the NAC1T. A reduction of the distance between the sill door and the engines has been observed on the latest generation of widebody aircraft as well, which has caused incidents at the gate. The introduction of fail-safe technologies (e.g., collision-avoidance systems and self-parking PBBs) have the potential to reduce the likelihood of a collision with the left engine when approaching the door.

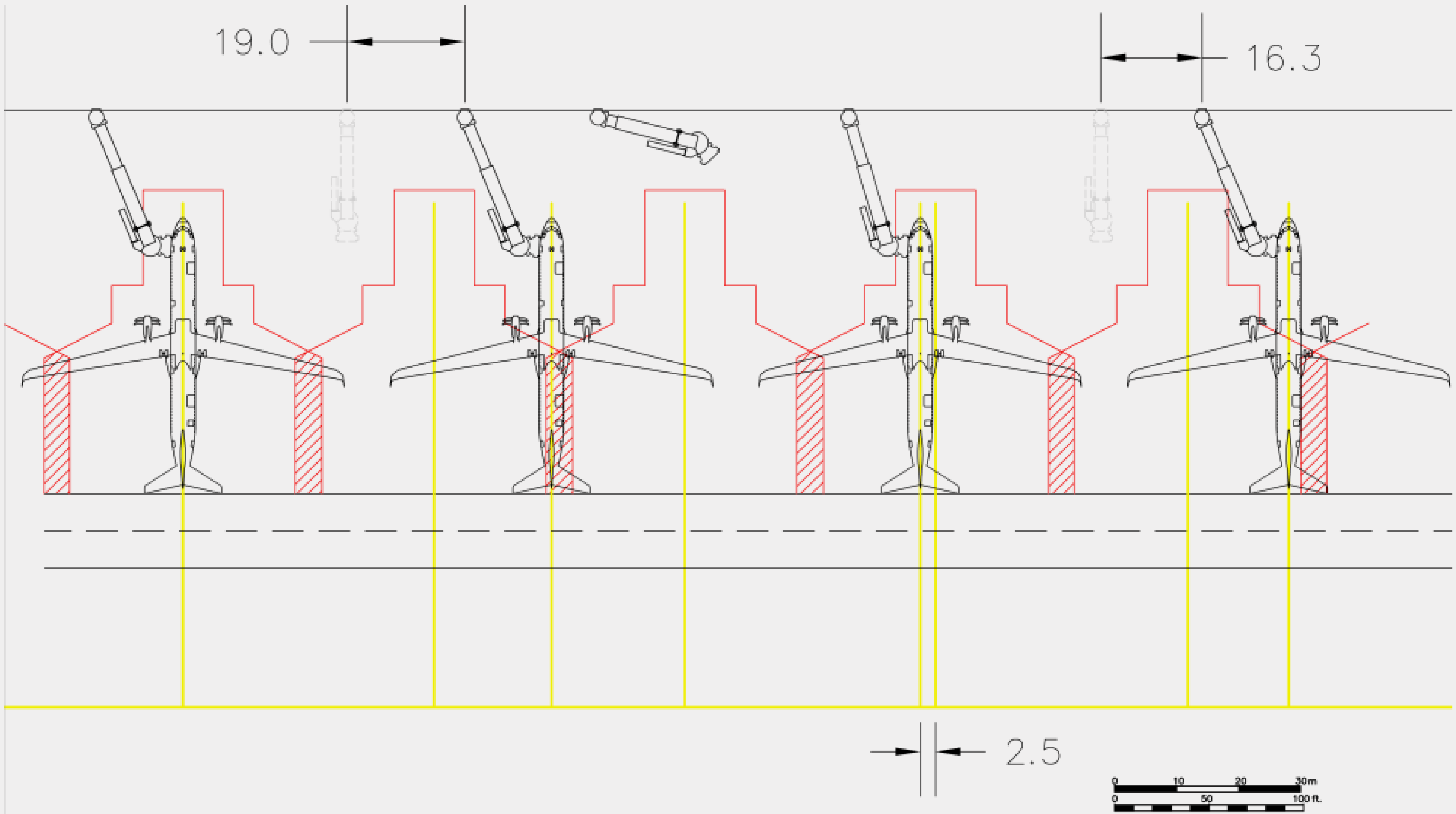
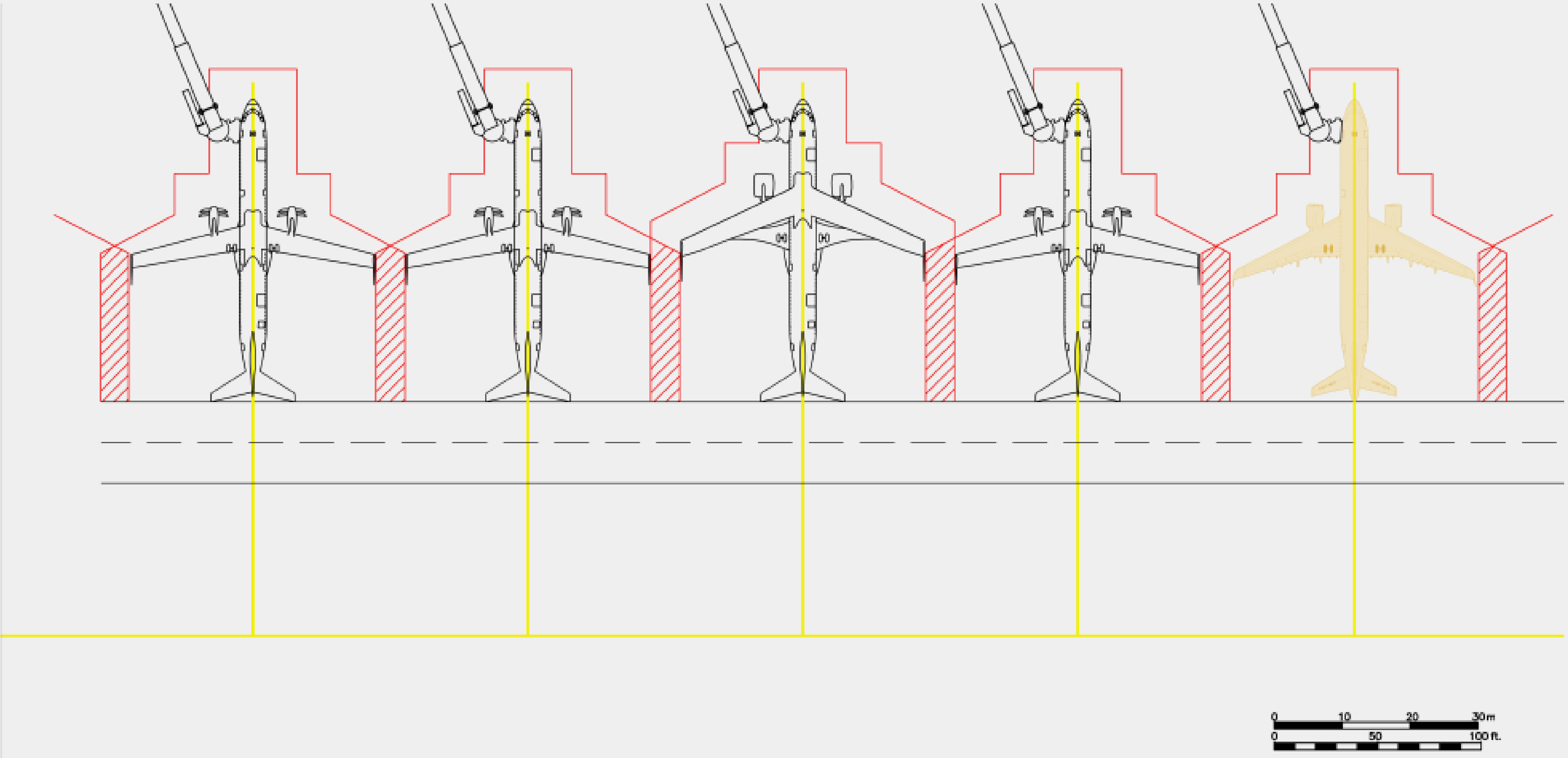


FIGURE 52. GATE RE-LOCATION ENABLING ALL-UNFOLDED NAC1P PARKING AT THE BASE-LINE CODE C APRON

FIGURE 53. BASELINE CODE C APRON WITH EXISTING AND NEXT GENERATION NARROWBODY AIRCRAFT



NAC2: BREAKING AWAY FROM "TUBE-AND-WING" FOR THE MIDDLE OF THE MARKET IN 2040

DESCRIPTION:

The NAC2 aircraft is a partially turboelectric middle-of-the-market aircraft adopting a flying wing configuration–also known as a blended wing body (Figure 54). The NAC2 has roughly half of the length of the Boeing 767-400/-400ER for a similar wingspan (Code D) and seat capacity. Indeed, the unique shape of the BWB configuration provides a large cabin cross-section where more seats can be placed abreast.

The propulsion is provided by two parallel hybrid (electrically-assisted) UHBPR turbofans as well as a secondary distributed electric propulsion (DEP) system with the electrically-powered motors being located between the two fans. The energy source for the gas turbines can be Jet A (SAF), hydrogen, or even dual hydrogen-jet fuel. The BWB geometry facilitates the incorporation of cylindric liquid hydrogen tanks while leaving the space inside the wing available for jet fuel. Hydrogen could also be processed through fuel cells to power the DEP system as well as the electrically-assisted components of the turbofans, while being used as a jet fuel by these same turbofans.

This combination of technologies could reach maturity for commercial applications within 15 years–with an entry into service of the NAC2 at the 2040 horizon.

AIRPORT COMPATIBILITY:

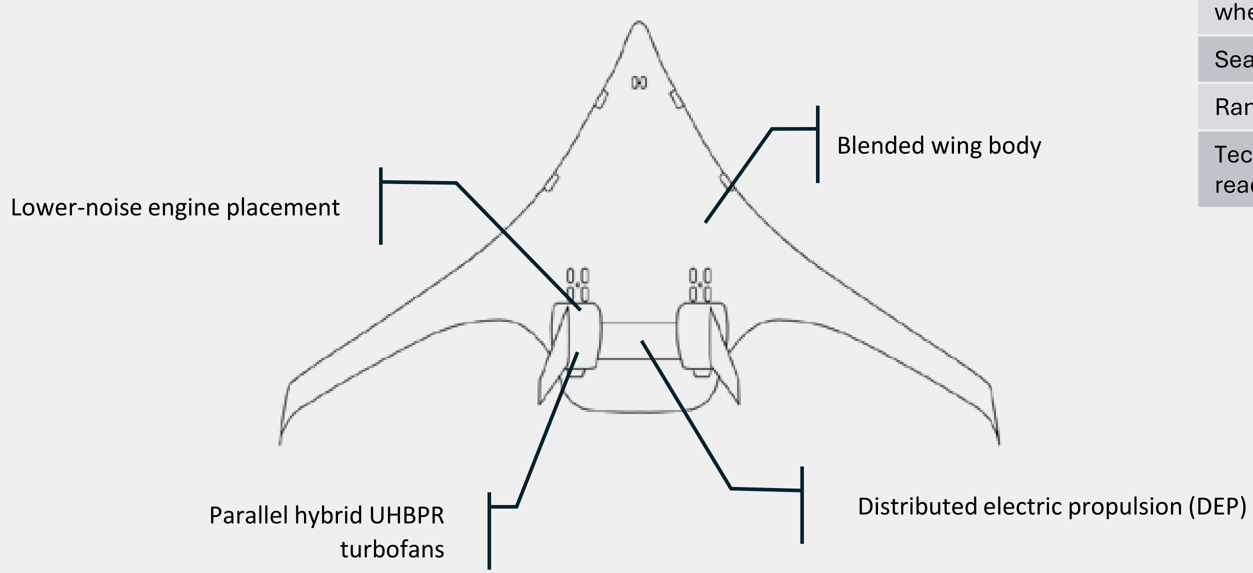
Compared to the tube-and-wing configuration, the BWB concept is more compact. For the same wingspan, the aircraft is dramatically shorter and occupies a smaller footprint. Therefore, folding wing technology is not a required feature for targeting markets currently operated with the Boeing 757/767 or Airbus A330/A330neo.

The determination of new stopline is a compromise to facilitate the operations of various ramp equipment and services at the gate, including but not limited to passenger deplaning and boarding, aircraft fueling, and power and air conditioning supply through fixed or mobile equipment. For instance, the NAC2 being shorter, maintaining the fuel vents within the reach of existing fuel pits servicing the Airbus 330 or Boeing 767 may lengthen the door-to-gate distance, therefore requiring jetbridges to extend farther.

The NAC2 adopts the same outer main gear wheel span (OMGWS) than the Boeing 767-400 but it features shorter wheel base. Therefore, its wheel track is less demanding and it requires smaller taxiway fillets.

NAC2: Blended Wing Body Middle-of-the-Market

	NAC Aircraft	Comparable Aircraft (Baseline)
Model	NAC2	Boeing 767-400ER
Length	30.6 m	61.4 m
Wingspan	52.0 m *Code D/FAA ADG IV*	51.9 m *Code D/FAA ADG IV*
Outer main gear wheel span	10.36 m *FAA TDG 5*	10.9 m *FAA TDG 5*
Seats	250+	243-296
Range	Similar to Baseline	3,500-4,700 NM
Technology readiness	2040	Today



Related R&D:
Airbus ZEROe
Boeing BWB JetZero Z-5
NASA N3-X
Natilus Horizon
Rolls-Royce UltraFan

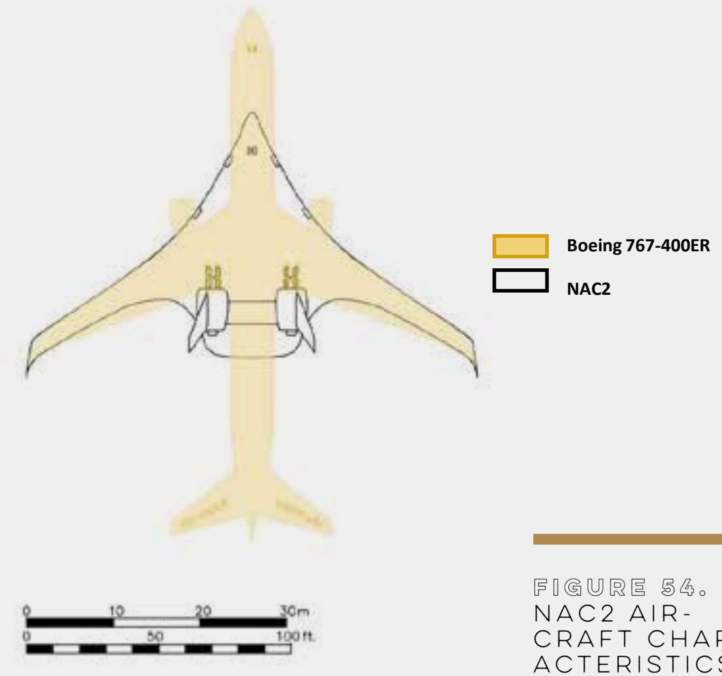


FIGURE 54. NAC2 AIRCRAFT CHARACTERISTICS

NAC3: FLYING LONG-RANGE WITH HYDROGEN-JET WIDEBODY AIRCRAFT IN 2045

DESCRIPTION:

The NAC3 aircraft depicts a concept pushing the tube-and-wing configuration to the limits (Figure 55). It carries as many passengers as an Airbus A330neo or Boeing 787-8. However, it requires a fuselage roughly the size of the proposed stretched Boeing 777-10X (nearly 80m-long) to store enough liquid hydrogen in aft and dorsal tanks to fly long-range routes.

The propulsion system includes two parallel hybrid UHBPR turbofans as well as an aft boundary-layer ingestion, electrically-driven fuselage fan (propulsive fuselage). Because of their dimensions, the turbofans cannot be accommodated conventionally under a low wing. They are rear-mounted on the NAC3. An overwing integration is another option being explored for future UHBPR engines.

Semi-aeroelastic hinged wingtips with folding wing technology provides a higher aspect ratio that promotes fuel savings without compromising airport compatibility. The aircraft has a Code F wingspan in the air that is reduced to a Code E wingspan on the ground after folding the wings.

This combination of technologies could reach maturity for a large widebody passenger airliner at the 2045 horizon.

AIRPORT COMPATIBILITY:

A NAC3 aircraft without folding wings cannot fit on an apron designed for Code E aircraft when other widebody (Code E) aircraft are parked on the adjacent gates. Indeed, the NAC3 with wings unfolded is a Code F aircraft. If the wings are folded to provide a wingspan reduction down to Code E, the aircraft can be accommodated at any Code E stand as long as the depth available can fit an 80-meter-long fuselage (Figure 57).

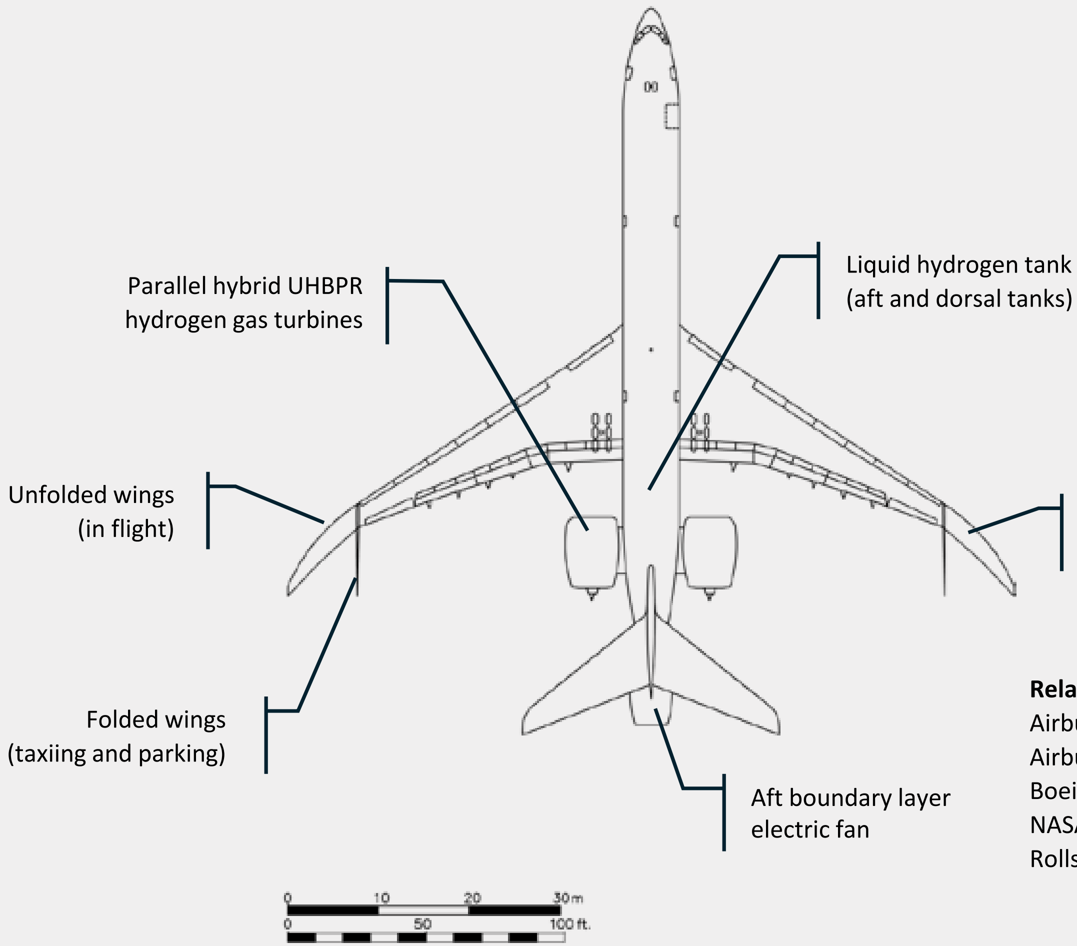
The length of the aircraft could be an issue at existing aviation facilities. Many hub airports have planned some of their aprons based on guidance from the International Industry Working Group specifying 80 m as a “preferred target [of overall length] for a new large aircraft”. The same document explains that “industry studies have shown that length of more than 80 m can be accommodated but infrastructure cost will rise sharply above 85 m”.

Figures 56–57 and 60–62 depicts gates designed based on this design aircraft assumption. Stands made for the Airbus A340-600 (63.5 m) or shorter aircraft may not accommodate this new long aircraft. Potential mitigation could include new angled lead-in line, reduced nose-to-building separations, and/or encroachment on vehicle service roads–similarly to those applied when the first “New Large Aircraft” (A340-600 and Boeing 777-300ER) were introduced.

The landing gear configuration features the wheel span of the Boeing 777-8/-9 but a significantly longer wheel base. This can make taxiing in curve challenging depending on the technique used to make the maneuver. Assuming a curved taxiway with fillets compatible with the most demanding aircraft (e.g., 777-9, A340-600, A380-800) and following the FAA TDG-6 design standards, the NAC3 can maintain a 4-meter clearance between its outer main wheels and the taxiway edge if it follows the nose gear-over-centerline technique. Performing a cockpit-over-centerline maneuver provides less than 1 meter of margin (Figure 58).

These gear characteristics might warrant external camera systems or other taxiing aid systems like those equipping some of the most taxiway fillet-demanding airliners. The FAA bases its Taxiway Design Groups on the cockpit-to-main gear distance (CMG) and main gear width (MGW). The NAC3 has a 43-m (141-ft.) CMG and is, therefore, off-chart for the FAA TDG criteria.

NAC3: Widebody Hydrogen Jet Aircraft



	NAC Aircraft	Comparable Aircraft (Baseline)
Model	NAC3	Boeing 777-9
Length	78.9 m	76.7 m
Wingspan (wings folded)	65.0 m *Code E/FAA ADG V*	64.9 m *Code E/FAA ADG V*
Wingspan (wings unfolded)	80.0 m *Code F/FAA ADG VI*	72.7 m *Code F/FAA ADG VI*
Outer main gear wheel span	12.8 m *FAA TDG 6**	12.8 m *FAA TDG 6*
Seats	210-250	349–426
Range	7,300 NM	7,285 NM
Technology readiness	2045	Today

**Based on wheelbase. The cockpit-to-main gear distances of 43 m (NAC3) is too great and is off-chart for the FAA TDG criteria.*

Related R&D:
Airbus AlbatrossONE
Airbus ZEROe
Boeing 777X
NASA STARC-ABL
Rolls-Royce UltraFan

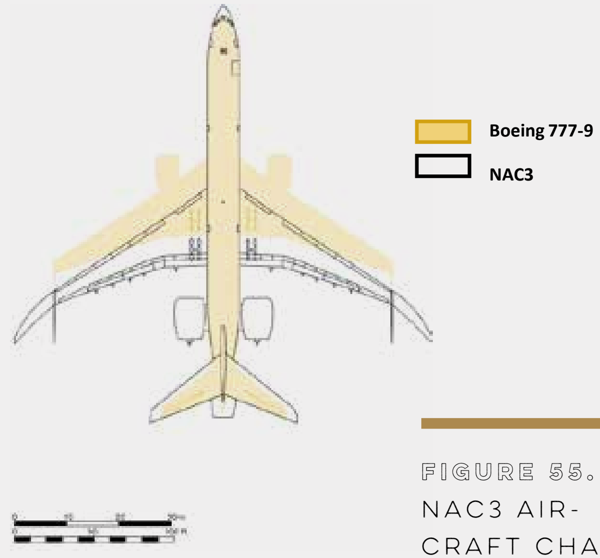
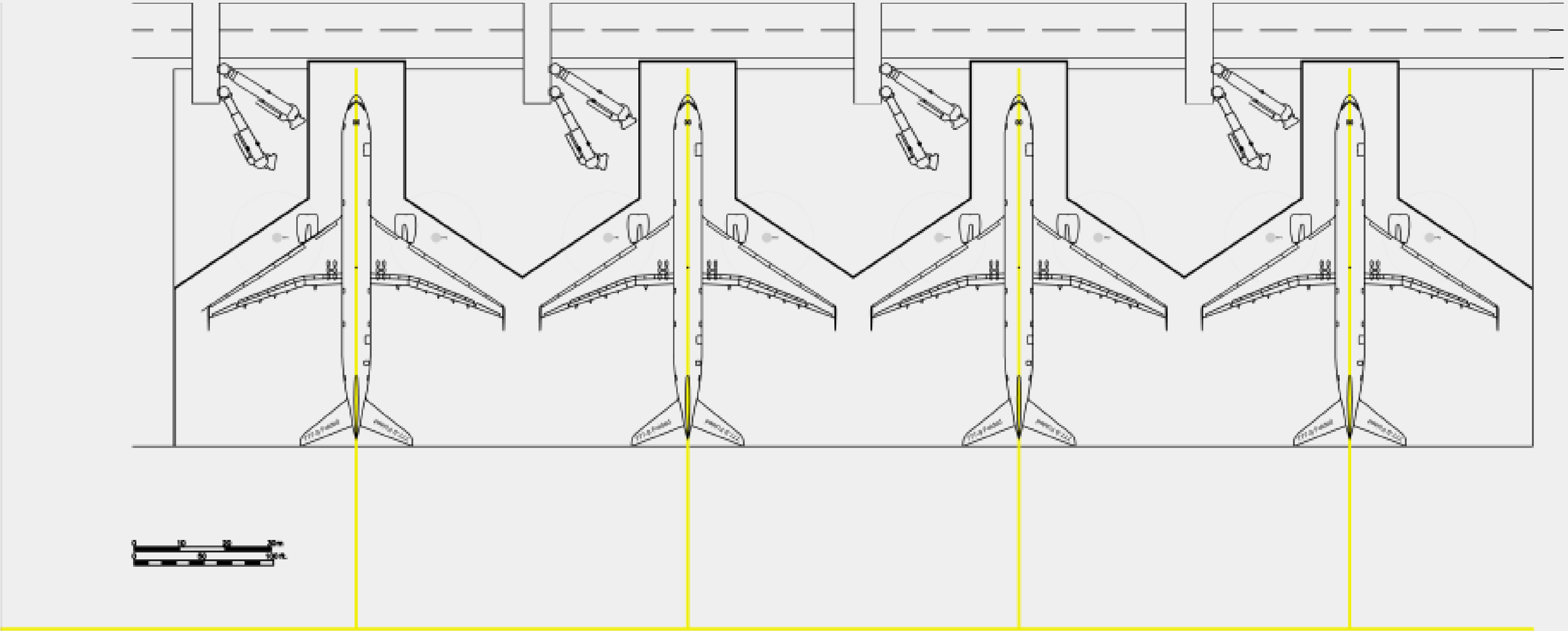


FIGURE 55. NAC3 AIRCRAFT CHARACTERISTICS

FIGURE 56.
BASELINE CODE E APRON WITH 777-9



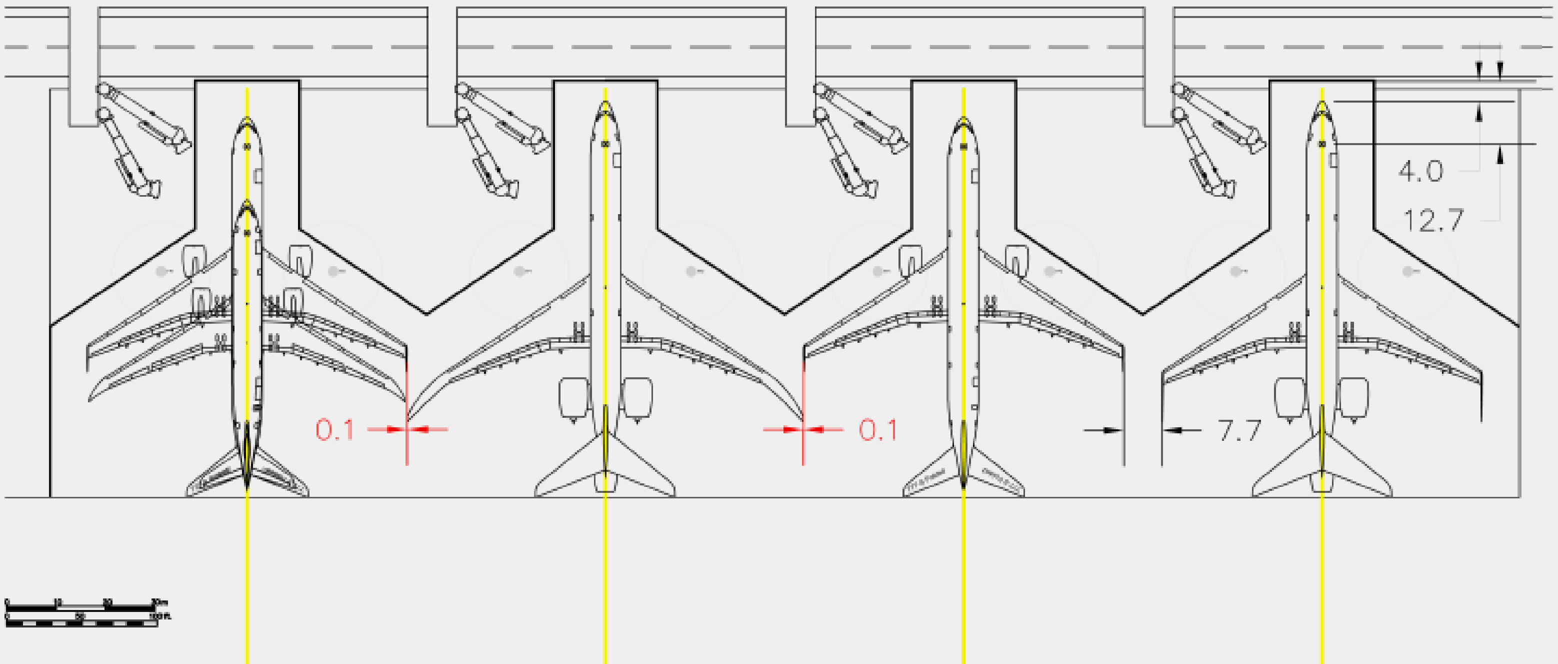
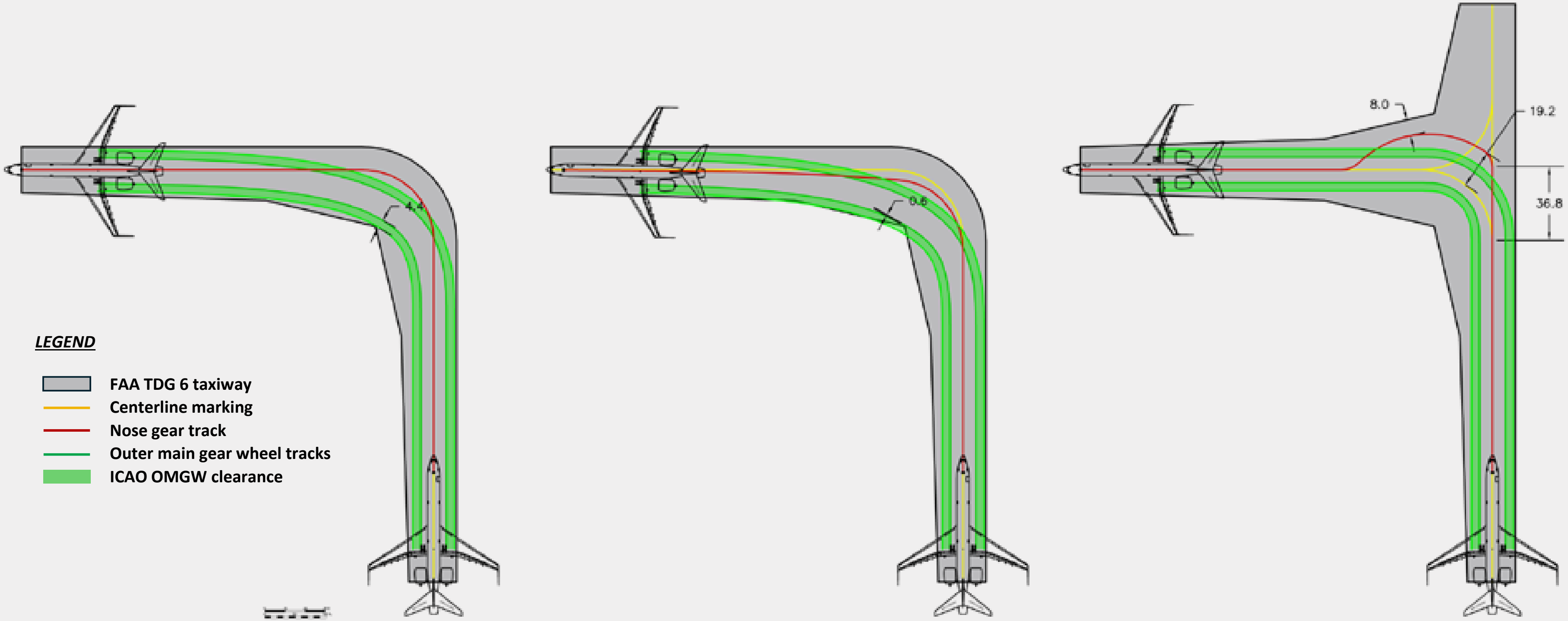


FIGURE 57.
BASELINE CODE E APRON WITH FOLDED AND UNFOLDED NAC3 AIRCRAFT

FIGURE 58. NAC3 AIRCRAFT MANEUVERS IN CURVES



NAC3 aircraft taxiing with nose gear centered on taxiway

NAC3 aircraft taxiing cockpit over centerline

NAC3 aircraft performing a judgmental oversteering

NAC4: ENABLING LOW-BOOM COMMERCIAL SUPERSONIC FLIGHTS BY 2050

DESCRIPTION:

The NAC4 aircraft is a second-generation supersonic airliner breaking with past and current designs by adopting boom-reduction technologies (Figure 59). These include low-boom aerodynamic shape and features inspired by past and ongoing research in this domain including those of the NASA QueSST program. The NAC4 achieves a passenger capacity, cabin space, range, and mission profile similar to Concorde's. Under these conditions, low-boom design promotes a needle-shaped fuselage that is roughly 50% longer than the previous generation of supersonic transporters. The morphing retractable nose is a proposed device reducing the supersonic boom when deployed in flight and mitigating gate compatibility issues on the ground (reducing the total length of the aircraft when retracted).

The NAC4 aircraft assumes progress in higher medium-bypass ratio engines with variable cycle engines and low-shock nacelles. Combining all these innovations could mitigate the sonic boom to an intensity allowing supersonic flights over land within designated corridors. Adapted flight procedures and the aforementioned innovations could provide for achieving ICAO Chapter 14 noise levels equivalent to those of existing subsonic airliners.

The engines are running on Jet A. While hydrogen can be used to power a supersonic plane, opportunities to store liquid hydrogen on the NAC4 would be very limited. Scaling up the concept for freeing space for hydrogen tanks and meet the mission requirements would make the aircraft even longer.

Technology readiness for a commercial aircraft based on these principles could be achieved by 2050.

AIRPORT COMPATIBILITY:

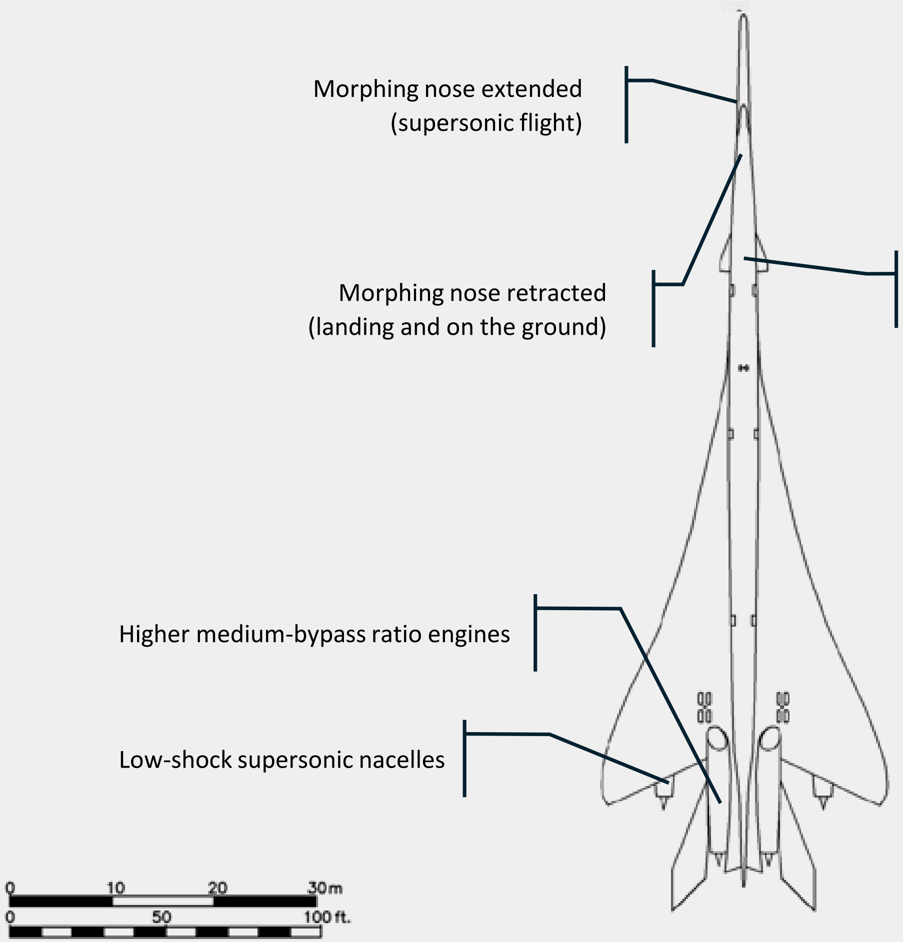
The NAC4 aircraft with its nose deployed is nearly 90-meter long. This length is incompatible with the large majority of existing aircraft stands at commercial airports. Design provisions for 80- or 85-meter long airliners that may have been made at large hub airports are not enough for accommodating a NAC4 aircraft on existing lead-in lines unless the plane is equipped with a device for reducing its length.

Concorde's nose could be tilted down to reduce drag and improve visibility during landing, taxiing, and takeoff operations. It is suggested that second-generation supersonic aircraft could adopt a similar feature (folding or retractable nose) designed to also achieve overall length reduction, as depicted on Figure 60.

However, even with a retractable nose, the aircraft would still be among the longest commercial passenger aircraft. Accommodating the NAC4 might warrant a secondary lead-in line, angled enough for fitting it diagonally. This solution might require a longer passenger boarding bridge and warrant the relocation of fuel pits (Figure 61–62).

The landing gear configuration features the wheel span of Concorde but significantly longer nose gear-to-main gear and cockpit-to-main gear distances. Assuming a curved

NAC4: Low-Boom Supersonic Airliner



	NAC Aircraft	Comparable Aircraft (Baseline)
Model	NAC4	Concorde
Length (nose extended)	88.9 m	61.7 m
Length (nose retracted)	80.0 m	N/A
Wingspan	28.3 m *Code C/FAA ADG III*	25.6 m *Code C/FAA ADG III*
Outer main gear wheel span	8.88 m *FAA TDG 6**	8.88 m *FAA TDG 6*
Seats	90-100	92-120
Range	Similar	3,900 NM
Technology readiness	2050	Decommissioned

**Based on wheelbase. The cockpit-to-main gear distance of 48 m (NAC4) is too great and is off-chart for the FAA TDG criteria.*

Related R&D:
Gulfstream X-54A
Gulfstream Quiet Spike
Lockheed Martin X-59
NASA QueSST
SAI QSST

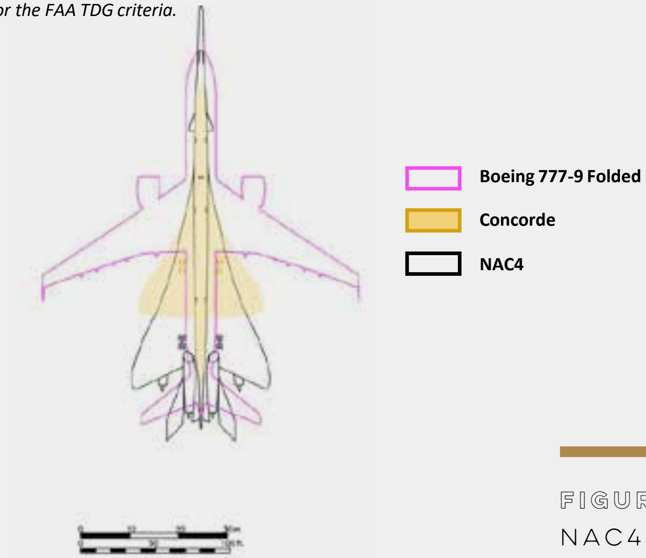
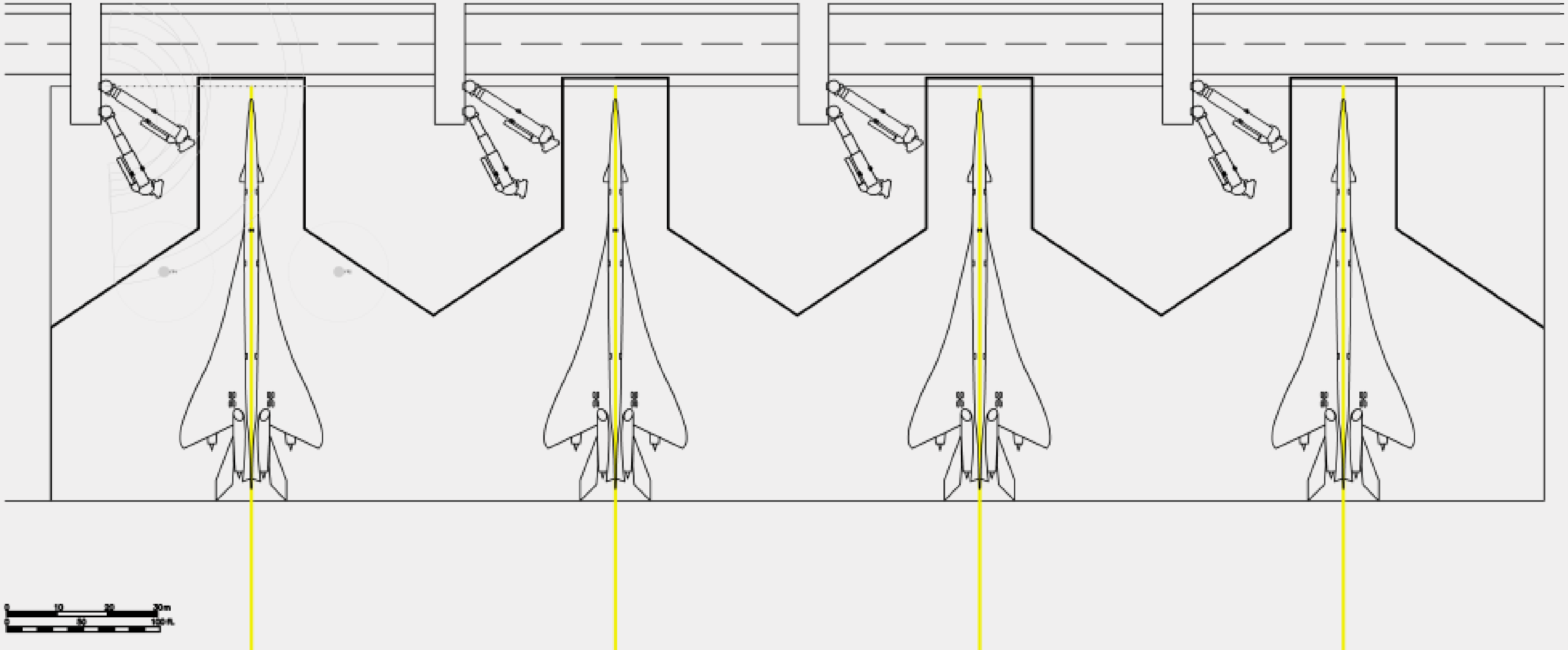


FIGURE 59. NAC4 AIRCRAFT CHARACTERISTICS

FIGURE 60. BASELINE CODE E APRON WITH NAC4 AIRCRAFT (NOSE RETRACTED)



taxiway with fillets compatible with the most demanding commercial aircraft and following the FAA TDG-6 design standards, the NAC4 can maintain a 4-meter clearance with the taxiway edge if it follows the nose gear-over-centerline technique. A cockpit-over-centerline maneuver provides less than 3 meters of margin (Figure 63).

External camera systems or other taxiing aid systems might be needed to facilitate safe taxiing operations and prevent excursions. The FAA bases its Taxiway Design Groups on the cockpit-to-main gear distance (CMG) and main gear width (MGW). The NAC4 has a 48-m (157-ft.) CMG which makes it off-chart for the FAA TDG criteria.

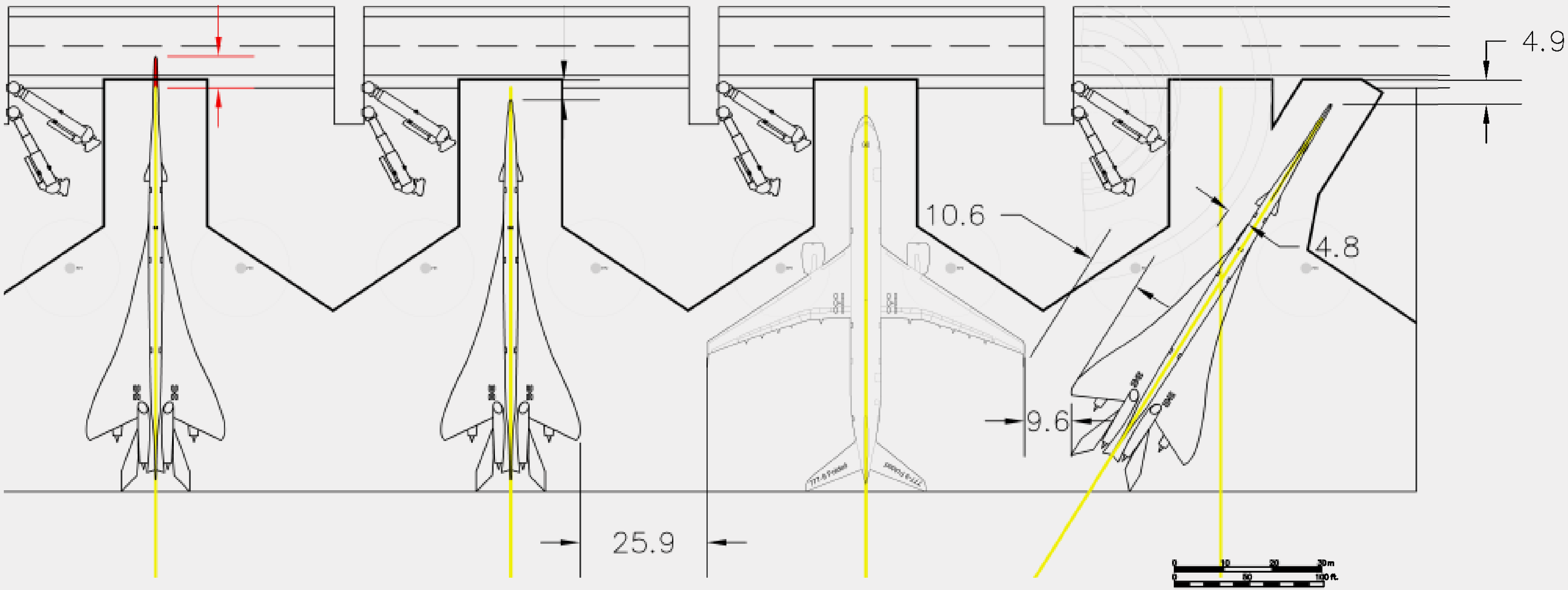


FIGURE 61. BASELINE CODE E APRON WITH VARIOUS NAC4 AIRCRAFT PARKING OPTIONS

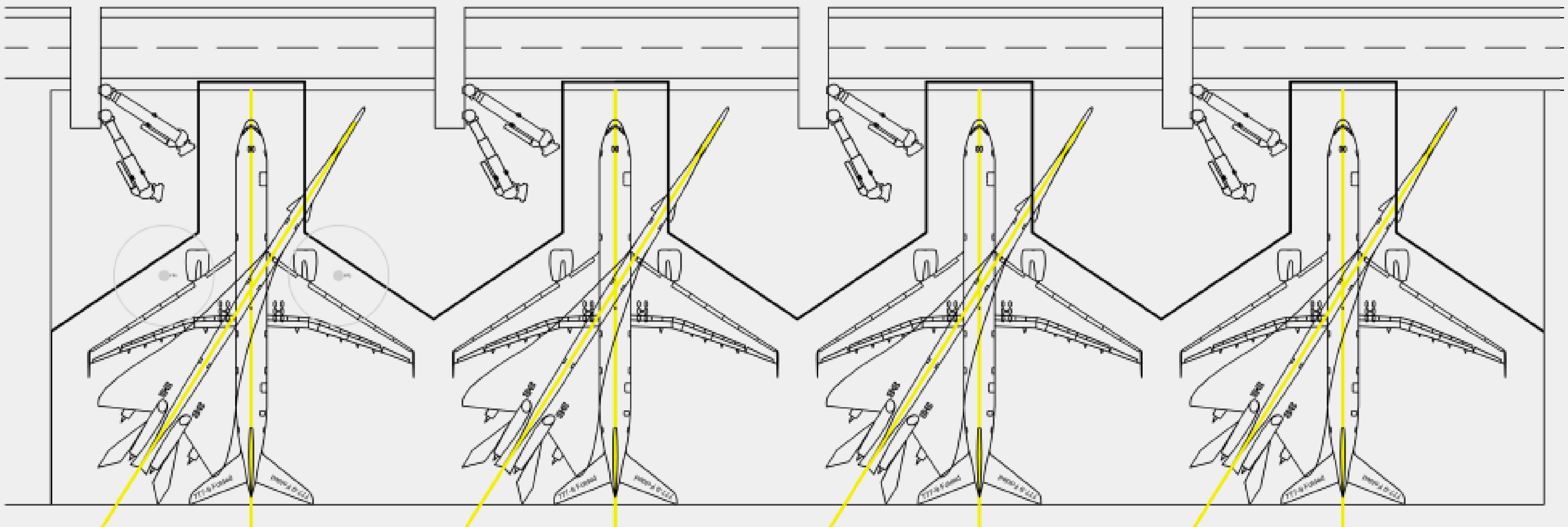
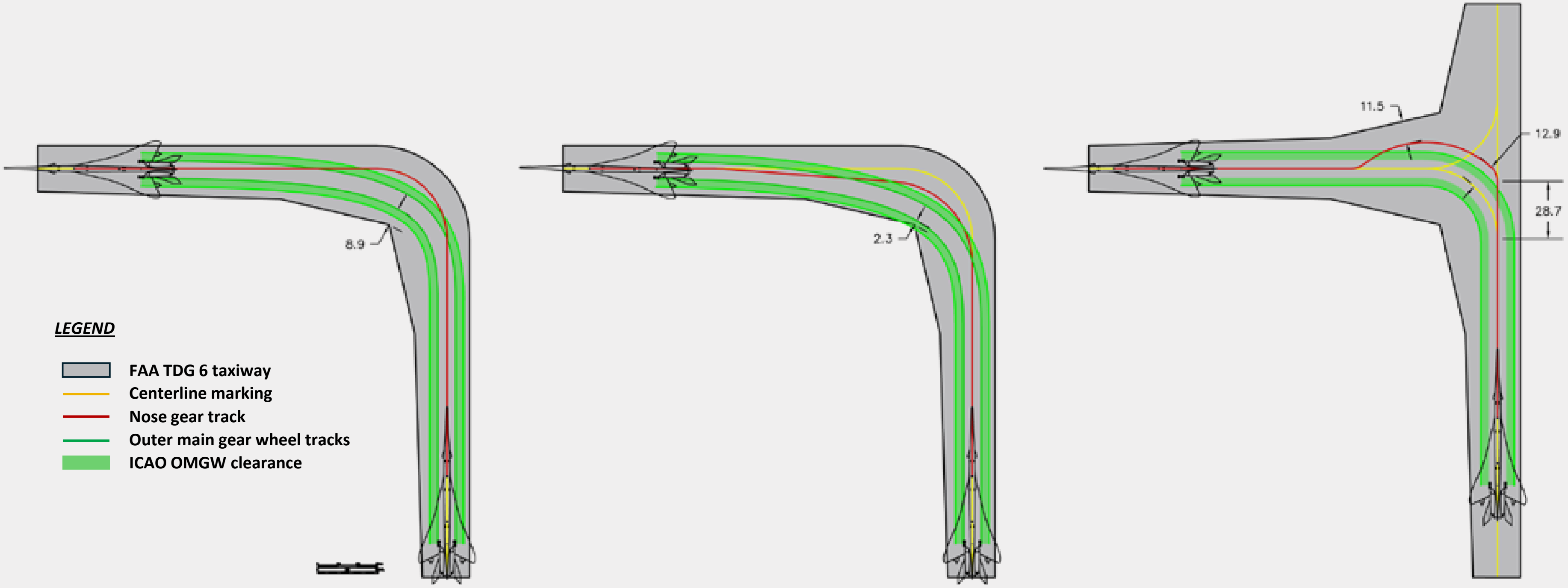


FIGURE 62. BASELINE CODE E APRON WITH SECONDARY LEAD-IN LINES FOR NAC4 AIRCRAFT

FIGURE 63.
NAC4 AIRCRAFT MANEUVERS IN CURVES



NAC4 aircraft taxiing
with nose gear centered on taxiway

NAC4 aircraft taxiing
cockpit over centerline

NAC4 aircraft performing
a judgmental oversteering

TABLE 12. MINIMUM APRON LINEAR FOOTPRINT FOR NOTIONAL FUTURE AIRCRAFT CONCEPTS

AIRCRAFT TYPE	WINGSPAN (IN M)	MINIMUM APRON LINEAR FOOTPRINT (LENGTH) FOR 90° AIRCRAFT STANDS (IN M)						MINIMUM CLEARANCE (IN M)
		1	5	10	15	20	25	
NAC Regio	36.0	45.0	207.0	409.5	612.0	814.5	1,017.0	4.5
NAC1	36.0	45.0	207.0	409.5	612.0	814.5	1,017.0	4.5
NAC1 (wings unfolded)	52.0	67.0	305.0	602.5	900.0	1,197.5	1,495.0	7.5
NAC2	52.0	67.0	305.0	602.5	900.0	1,197.5	1,495.0	7.5
NAC3	65.0	80.0	370.0	732.5	1,095.0	1,457.5	1,820.0	7.5
NAC3 (wings unfolded)	80.0	95.0	445.0	882.5	1,320.0	1,757.5	2,195.0	7.5
NAC4	28.3	37.3	168.5	332.5	496.5	660.5	824.5	4.5
Code A	15.0	21.0	93.0	183.0	273.0	363.0	453.0	3.0
Code B	24.0	30.0	138.0	273.0	408.0	543.0	678.0	3.0
Code C	36.0	45.0	207.0	409.5	612.0	814.5	1,017.0	4.5
Code D	52.0	67.0	305.0	602.5	900.0	1,197.5	1,495.0	7.5
Code E	65.0	80.0	370.0	732.5	1,095.0	1,457.5	1,820.0	7.5
Code F	80.0	95.0	445.0	882.5	1,320.0	1,757.5	2,195.0	7.5
Concorde	25.6	34.6	155.0	305.5	456.0	606.5	757.0	4.5
ATR 72-600	27.1	36.1	162.5	320.5	478.5	636.5	794.5	4.5
A321neo	35.8	44.8	206.0	407.5	609.0	810.5	1,012.0	4.5
767-400ER	51.9	66.9	304.5	601.5	898.5	1,195.5	1,492.5	7.5
777-9 (FWT up)	64.9	79.9	369.5	731.5	1,093.5	1,455.5	1,817.5	7.5

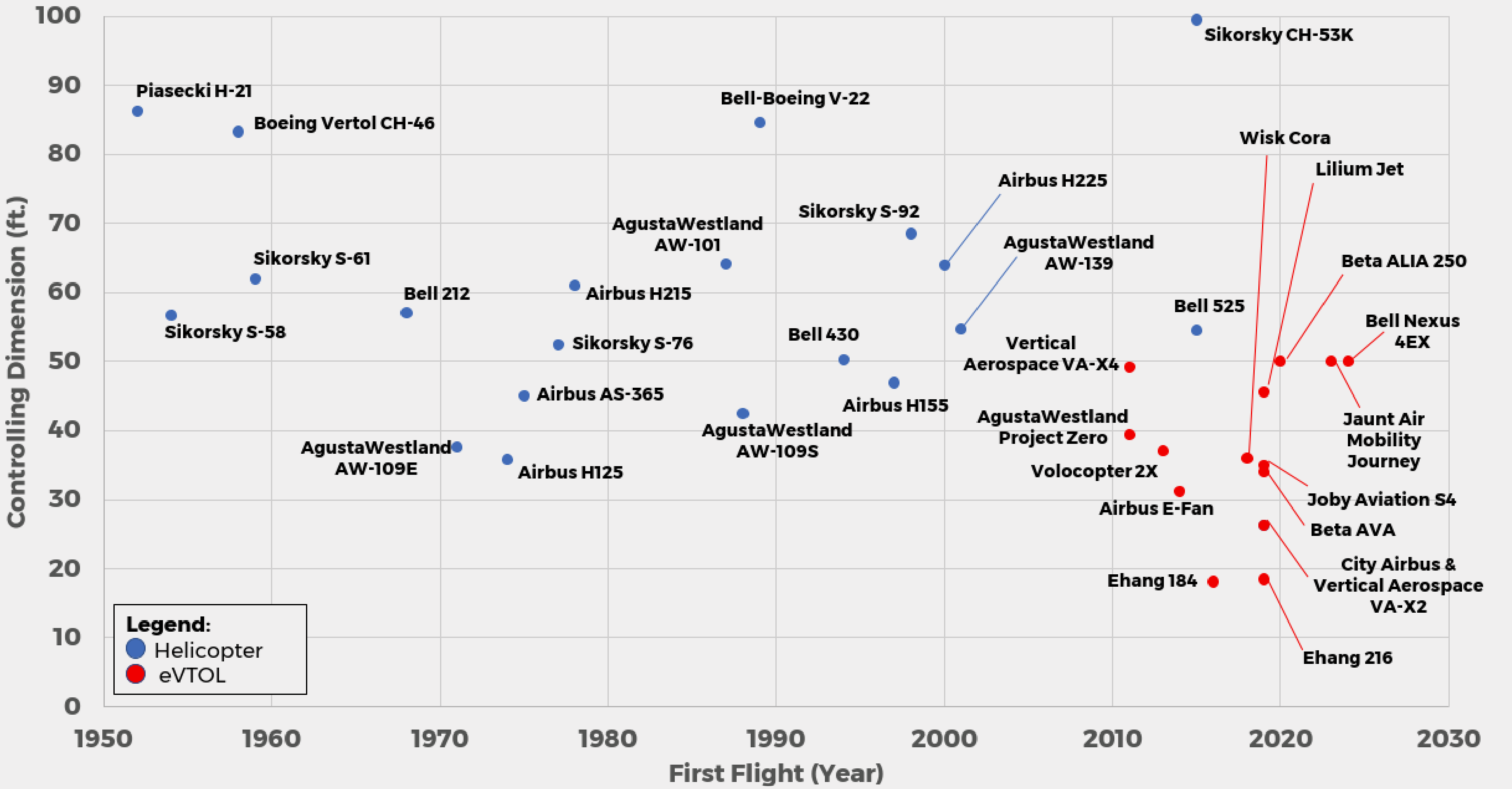


FIGURE 64. EVOLUTION ON THE CONTROLING DIMENSION OF TRANSPORT VTOL AIRCRAFT

Source: Le Bris & Nguyen (2023)

MATURITY STATE	UML	DESCRIPTION
Initial State	UML-1	Late-Stage Certification Testing and Operational Demonstrations in Limited Environments Aircraft certification testing and operational evaluations with conforming prototypes; procedural and technology innovation supporting future airspace operations (e.g. UTM-inspired); community/market demonstrations and data collection.
	UML-2	Low Density and Complexity Commercial Operations with Assistive Automation Type certified aircraft; initial Part 135 operation approvals; limited markets with favorable weather and regulation; small UAM network serving urban periphery; UTM construct and UAM routes supporting self-managed operations through controlled airspace.
Intermediate State	UML-3	Low Density, Medium Complexity Ops with Comprehensive Safety Assurance Automation Operations include urban core; operational validation of advanced airspace operations and management including UTM inspired ATM, CNSI, C2, and automation for scalable, weather-tolerant operations; few high-capacity aerodromes; noise compatible with urban soundscape; model-local regulations.
	UML-4	Medium Density and Complexity Ops with Collaborative and Responsible Automated Systems Hundreds of simultaneous operations; expanded networks including closely spaced high throughput aerodromes; many UTM inspired ATM services available, simplified aircraft operations for credit; low-visibility operations.
Mature State	UML-5	High Density and Complexity Operations with Highly Integrated Automated Networks Thousands of simultaneous operations; large-scale, highly distributed networks; high-density UTM inspired ATM; autonomous aircraft and remote, M:N fleet management; high-weather tolerance including icing; high-volume manufacturing.
	UML-6	Ubiquitous UAM Operations with System-Wide Automated Optimization Tens of thousands of simultaneous operations (capacity limited by physical infrastructure); ad hoc landing sites; noise compatible with suburban/rural operations; private ownership & operation models enabled; societal expectation.

TABLE 13. NASA URBAN AIR MOBILITY MATURITY LEVELS (UML)

Source: NASA (2020)

APPENDIX M

CATEGORIZATION OF VTOL AIRCRAFT FOR VERTIPORT PLANNING

CONTEXT

Aerial vehicles for urban air mobility may open new markets for mobility providers and flight operators thanks to their lower operating costs. In return, this may increase the passenger demand. Some vertiports might accommodate high-intensity VTOL operations in stark contrast with today's heliports. UAM will leverage existing heliports and also require the development of new vertiport facilities to accommodate the future demand. It is estimated that enabling UAM services in 74 cities around the world will require about $30 billion over the next two decades[361]. Also, the broad variety of eVTOL aircraft under development constitutes a menagerie of different configurations and dimensions. Under these conditions, the categorization of VTOL aircraft can help aircraft designers and facility planners to get a better understanding of the resource available on the ground, the physical constraints to access markets, and the VTOL fleet mix.

VTOL AIRCRAFT CONTROLLING DIMENSION

As aviation is experiencing the dawn of electric VTOL aircraft, different national aviation authorities have published prototype standards to provide guidance to the advanced air mobility community for the planning and design of vertiports. For instance, the European Union Aviation Safety Agency and the U.S. Federal Aviation Administration have released the PTS-VPT-DSN Issue No. 1 and Engineering Brief (EB) No. 105, respectively.

An equivalence between helicopter and non-helicopter VTOL concepts is needed when considering the accommodation of all VTOL aircraft at helicopter facilities, and vice versa. Furthermore, the ICAO Annex 14 and national standards on heliports and vertiports can have slightly different definitions for the main dimensional criteria used for airfield design purpose. The term "controlling dimension" or CD refers to the controlling dimension D per FAA AC 150/5390-2D for helicopters, and the CD per FAA EB No. 105 for non-helicopter VTOL aircraft. Table 2 compares these definitions.

STANDARDS	PUBLICATION	DEFINITION
ICAO Annex 14 Vol. II – Heliports	2018	The largest overall dimension D of the helicopter when rotor(s) are turning measured from the most forward position of the main rotor tip path plane to the most rearward position of the tail rotor path plan or helicopter structure.
FAA AC 150/5390-2D: Heliport Design	2023	D is the greater of helicopter's overall length OL and overall width OW.
FAA EB No. 105: Vertiport Design	2023	Diameter CD of the smallest circle enclosing the VTOL aircraft projection on a horizontal plane.

TABLE 14. DEFINITIONS OF THE CONTROLLING DIMENSION

VTOL AIRCRAFT DESIGN GROUPS

Five VTOL aircraft design groups or VDGs (Table 15) are proposed for facilitating vertiport planning. These VDGs were developed based on a careful review of existing helicopters used for providing on-demand transportation, of ongoing eVTOL aircraft projects, and of the existing heliport infrastructure[362]. The VDGs group VTOL together according to their controlling dimensions (Fig. 65). Each group of VTOL aircraft is associated with different aerial mobility market segments. These proposed VDGs could play a similar role than the ICAO Letter of Code or the FAA Airplane Design Group (ADG) in providing a common framework to aircraft developers, airport operators, and their stakeholders.

VDG	CD (M)	CD (FT)	EXISTING VTOL EXAMPLE	FUTURE VTOL EXAMPLE	MARKET SEGMENTS
1	x≤10	x≤33	Guimbal Cabri G2	EHang 216	Small VTOL aircraft
2	10<x≤12	33<x≤40	Airbus H125	Joby Aviation S4	Light helicopters Most 2- to 4-seater eVTOLs
3	12<x≤15	40<x≤50	AugustaWestland AW109S	Beta Alia-250	Light-medium helicopters All urban air mobility
4	15<x≤20	50<x≤65	Bell 525	Leonardo NGCTR	Medium and super-medium helicopters
5	x>20	x>65	Sikorsky S-92	Bell V-280	Heavy transport and lift helicopters Large VTOL for regional air mobility

TABLE 15. DEFINITION OF VTOL DESIGN GROUPS

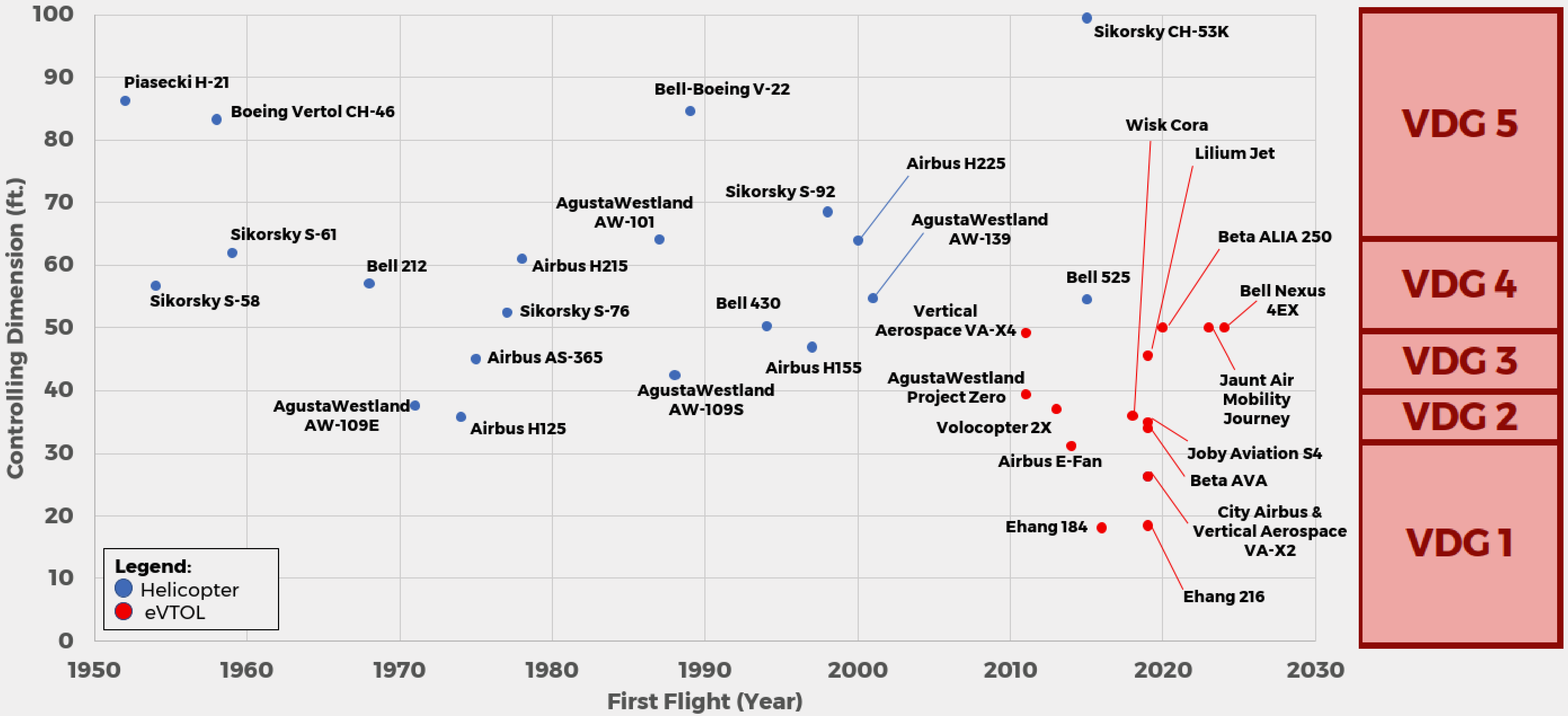


FIGURE 65. VDG CATEGORIZATION OF VTOL AIRCRAFT

INTRA-AIRPORT MOBILITY SOLUTIONS EVALUATION TOOL

This planning tool provides guidance to airport practitioners for comparing and evaluating different solutions to provide passenger conveyance and mobility within the airport boundary. The guidance references and combines previous research efforts andindustry documents (e.g., ACRP, IATA). The resulting tool proposes criteria and a step-by-step methodology for supporting the decision-making process.

HOW TO USE THIS TOOL

The term STOP HERE ends the workflow and identifies a potential solution.

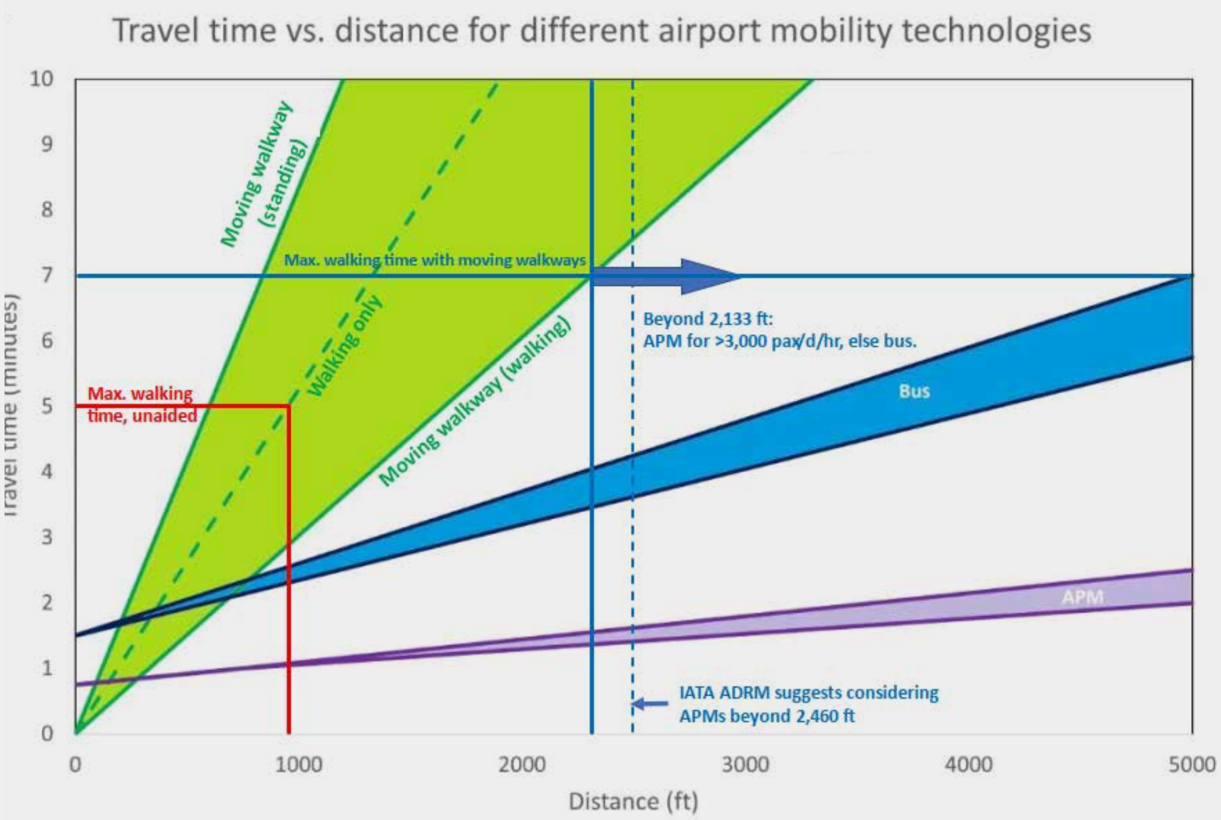


FIGURE 66. INTRA-AIRPORT MOBILITY SOLUTIONS EVALUATION TOOL

1. Determine the path where a mobility solution is needed. This can be both within an airport terminal (such as between gates) or between airport facilities (such as terminals to/from ground transportation centers)

2. Evaluate whether travel distance(s) meet walking time limits. Guests should not have to walk more than 5 minutes unaided (approximately 900 ft.).
   • If the travel time meets these limits: STOP HERE.

3. Evaluate whether moving walkways would be sufficient. Moving walkways are suitable as long as guests can cover the travel distance within 7 minutes while using the walkways and walking (approximately 2,133 ft.).
   • If the travel time meets these limits: STOP HERE. Walkways can be a potential solution.

4. If walkways are not a potential solution. Buses and automated people movers (APMs) are potential solutions for longer distances, based on the expected travel volume.
   • If the travel volume exceeds 3,000 users/direction/hour: APM is a potential solution.
   • Else: Bus shuttles are potential solutions.

THREAT	RECENT EXAMPLES	TYPICAL EFFECTS ON AIR-PORTS	GLOBAL MITIGATION	AIRPORT-SPECIFIC ACTIONS
Pandemics and epidemics	Ebola, SARS, MERS, COVID-19, Zika	Short-term & brutal drop in air traffic and revenues, workforce on sick leave, overflow aircraft to store on airfield, etc.	International coordination, trans-national transparent collaboration, national readiness, enhanced hygiene, disease-specific actions (e.g., mosquito control, stay-at-home, etc.), change in social behaviors, economic relief plans, etc.	Airport response plan, prevention plan, designs preventing airborne spread, regular cleaning of parts touched by passengers and workers, soap and hand sanitizer available, prevention voice messages in terminal buildings, specific measure toward arriving passengers, etc.
Climate change-induced extreme weather	Hurricane Barry, Hurricane Catarina, Typhoon Jebi	Interruption of air traffic, destruction of facilities, higher operating costs and capital expenditures, etc. *Note: climate change might create favorable conditions for a wider spread of mosquito-borne diseases.*	Climate resilience, strong reduction of overall carbon emissions and “negative emissions”, etc.	Airport climate resilience plan, incorporation of future climate in planning & design, financial resilience to more regular extreme weather conditions, etc.
Terrorism	Salafi jihadism, white supremacism, radical anarchism, murder-suicide patterns	Medium-term drop in air traffic and revenues, etc.	Global War on Terrorism, intelligence and police efforts, state security strategies, mitigating the roots of terrorism, etc.	ICAO GASeP, local implementation of state security plan, secure-by-design facilities, airport community awareness programs, etc.
Cyberwarfare	State-sponsored cyberattacks	Power outages, systems are out of service, malicious diversion of systems, etc.	National cyber-counter terrorism, cooperation between intelligence community and industry, etc.	IT system hardening, redundancies, operational resilience with low-tech contingency plans, etc.
Conventional warfare	Libyan Civil War, War in Donbass	Drop in air traffic, destruction of facilities	Prevention of conflicts and promotion of enduring peace	Airport-to-airport mutual assistance, evacuation of civilian aircraft toward safe aviation facilities, etc.

TABLE 16.
LONG-TERM THREATS TO AIRPORT RESILIENCE

TABLE 17. EXISTING AND EMERGING MODES OF TRANSPORTATION TO AIRPORTS

MODE OF TRANSPORTATION	EXAMPLES	ENTRY INTO SERVICE	DESCRIPTION AND OPPORTUNITY FOR AIRPORTS
Direct Express Train	AirTrain-JFK Express (JFK), CDG Express (CDG), Heathrow Express (LHR), Gatwick Express (LGW), Flytoget (OSL), KLIA Ekspres (KUL), Skytrain (CGK)	1970s	Direct Express trains usually make a small number of stops, usually major destinations, allowing faster service than local trains that stop at most or all of the stations along their route. Airports utilize this mode of transportation for faster commutes for passengers, unlike the normal trains.
Metro Rail, Light Rail and Regional Train	Berlin U-Bahn (BER), Blue Line (ORD), RER B (CDG), CPMT Line 13 (GRU), OrlyVAL-RER B (ORY), TER (MRS), VLT Carioca Linhas 1 e 3 (SDU), SRT Dark Red Line (BKK)	1972	Light rail is a form of passenger urban rail transit characterized by a combination of tram and metro feature. Utilization of light rail at airports will aid in the reduction of traffic congestion at the curbside of the airport and also reduce carbon emissions.
Bus Rapid Transit (BRT)	Linha 208 (CWB), Luton Busway (LTN), MICiTi (CPT), Transcarioca (GIG), Viva Canada (non-airport),	1973	BRT is a bus-based public transport system designed to improve capacity and reliability relative to a conventional bus system. BRTs are not new, but some regions of the world are not yet widespread to connect airport. Using BRTs at airports would cut down the travel times for passengers to reach their destinations or get to the airports since they have dedicated bus lanes, and also will help in the reduction of carbon emissions.
Personal Rapid Transit (PRT)	T5-Parking (LHR), Morgantown PRT (non-airport)	1975	The PRT is a public transport mode featuring small, automated vehicles operating on a network of specially built guideways. The PRT system in Heathrow will replace shuttle buses. This compared to the Airport People Movers (APMs) would result in short wait and trip times combined with seated travel to provide an exceptionally high level of service.

MODE OF TRANSPORTATION	EXAMPLES	ENTRY INTO SERVICE	DESCRIPTION AND OPPORTUNITY FOR AIRPORTS
High Speed Train (HST)	Brightline (Florida), ICE (Germany), TGV (France), InterCity 125 (Britain), Fuxing Hao Dolphin Blue (China), Haramain Western Railway (Saudi Arabia)	1964 (Shinkansen) 1994 (TGV at CDG)	High-speed train (HST) is a type of rail transport that runs significantly faster than traditional rail traffic, using an integrated system of specialized rolling stock and dedicated tracks. This system can connect customers from one point to another as fast as air travel.
Maglev	Shanghai Maglev Train (SMT)	2002	Maglev is a system of train transportation that uses two sets of magnets, one set to repel and push the train up off the track, and another set to move the elevated train ahead, taking advantage of the lack of friction. With the use of Maglev in airports, it can connect passengers to their final destinations quicker and more efficiently compared to other modes of transportation.
Transportation Network Companies	Lyft, Ola Cabs, Snapp, Uber, Cabify (Spain), Taxify/BOlt (Estonia), Grab (Singapore), Gett (Israel), Ola (India), DIDI (China), Shebah (Australia), TappCar (Canada), Enshika (Ghana)	2017 (Uber)	They offer door-to-door, nonstop transportation at the request of customers via smartphone applications, or apps, that the companies offer and operate. They have increased the transportation options available to airport customers by expanding the menu of available ground transportation services and, offering a service that customers consider to be reliable, convenient, and comfortable
Autonomous Personal Vehicles	None	2030?	AVs are vehicles where some aspects of a safety-critical control function such as steering, throttle control or braking occurs without direct driver input. This will reduce traffic congestions and aid in climate control by reducing CO_2 emissions
Electric Skates and High-Speed Tunnels	The Boring Company "Loop" a.k.a. The Elevator (prototype)	2025?	A concept of vehicles transported through tunnels on autonomous electric skates capable of carrying cars and people at speeds of up to 150 miles per hour. The most recent evolution of The Loop concept of the Boring Company does not feature electric skates anymore.

MODE OF TRANSPORTATION	EXAMPLES	ENTRY INTO SERVICE	DESCRIPTION AND OPPORTUNITY FOR AIRPORTS
Urban Air Mobility	Blade, Joby Aviation, Lilium	2030?	It is an on-demand and automated passenger and cargo air transportation services, typically without a pilot, also known as “flying taxis.” This mode of transportation will add to the industry’s stakeholder revenue, and also create more airport transportation jobs.
Vactrain/Hyperloop	Chicago Downtown-ORD (Project)	2030?	Vactrain/Hyperloop is a sealed tube or system of tubes through which a pod may travel free of air resistance or friction conveying people or objects at high speed while being very efficient, thereby drastically reducing travel times over medium-range distances. This may be an alternate option to air transport since it might be as fast or faster than flying.

LEVEL	LEVEL NAME	ADAS/ADS CAPABILITIES	SYSTEM PERFORMS ALL DRIVING TASKS
0	No Driving Automation	ADAS: Driver carries out all driving tasks but may be aided by active safety systems.	No
1	Driver Assistance	ADAS: System handles either lateral or longitudinal motion control, but not both.	No
2	Partial Driving Automation	ADAS: System handles lateral and longitudinal motion controls. Driver remains responsible for object and event detection and response.	No
3	Conditional Driving Automation	ADS: System can carry out tasks within its object design domain (ODD) but may require and notify a human driver to intervene (fallback).	Yes
4	High Driving Automation	ADS: System can carry out tasks within its ODD with no expectation for the user to intervene.	Yes
5	Full Driving Automation	ADS: System can carry out tasks, both within its ODD and not specific to it, without need for human intervention.	Yes

TABLE 18.
SAE'S LEVELS OF DRIVING AUTOMATION

Source: SAE International (2021)

TABLE 19. POTENTIAL DRIVING IMPLICATIONS OF DRIVING AUTOMATED FEATURES

Source: Le Bris et al. (2024)

SAE LEVEL	OUTSIDE OF AUTOMATED DRIVING SERVICE AREA	WITHIN AUTOMATED DRIVING SERVICE AREA
Level 0	Human driving (no assistance)	Human driving (no assistance)
Level 1	Human driving with ADAS	Human driving with ADAS
Level 2	Human driving with ADAS	Human driving with ADAS
Level 3	Human driving with ADS	Self-driving ADS with human override when necessary
Level 4	Human driving with ADS	Self-driving ADS (autonomous driverless mode)
Level 5	Not accessible	Self-driving ADS (autonomous driverless mode)

Note: This table assumes the automated driving service area is at least compatible with the SAE level of the vehicle equipment and systems and such features are activated when possible.