The Future of Airports

A Vision of 2040 and 2070

Topic No. 6: Airside & Airspace Compatibility

White Paper

ENAC Alumni – Airport Think Tank

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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, President of ENAC Alumni

Introduction

From March 2019 to April 2020, the Airport Think Tank of ENAC Alumni conducted a research project on the long-term future of the airport industry: “The Future of Airports”. The project involved thought aviation leaders from diverse backgrounds and affiliations who looked at the trends and potentially disruptive changes, emerging transformational innovations, their impact on practice and their challenges for air transportation, and the needs in research, education, and policies for anticipating and facilitating 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, we will count more fellow human beings than ever. Overall, we will be wealthier and more educated, and have a longer life expectancy. However, we will all face increased impacts from climate change that will put pressure on resources and communities, and might increase inequalities. We will have different social expectations. How can aviation address these new paradigms and continue to provide mobility?

First and foremost, we shall never forget that safety always comes first. As we are making air transportation increasingly automated and connected, we shall 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 greener if we want to sustain the development of our societies without degrading our well-being and endangering public health at a horizon increasingly visible. Aviation shall keep pioneering green policies.

As aviation professionals, we are on the front line to tackle the fundamental issues arising and still continue to interconnect people and move freight. Aviation shall remain a world of opportunities and “create and preserve friendship and understanding among the nations and peoples of the world” as stated in the Convention of Chicago of 1947.

By 2040 and 2070, it is likely that unforeseeable groundbreaking technological innovations, scientific discoveries, and social and political changes will occur and deeply impact our world. When reading these pages, remember that we conducted our work and prepared these materials with our eyes of 2019.

We are all part of this future, and we can make a difference individually if we make ethical and sustainable decisions. 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’s make a bright aviation future possible together.

Gaël Le Bris, Chair of the Airport Think Tank of ENAC Alumni

Topic No. 6: Airside & Airspace Compatibility

Diversity is in the Air

The fleet of aircraft in the field and in the air will become more diverse over the coming decades. The lower airspace might get busier in the coming 5 to 10 years. Urban and Rural (or Regional) Air Mobility (UAM/RAM) promises a new era of mobility with new vehicles that should be safer, cheaper, quieter and greener than today’s helicopters. Upon getting clearance from the regulators, they might enable an increase in capacity on intra- and perhaps inter-urban trips that are much needed in dense metropolitan areas with acute congestion issues. Urban Air Mobility will be provided by electric Vertical Takeoff and Landing (eVTOL) vehicles of various sizes moving 2 to 6 passengers or light freight. Services will include air taxi by manned electric helicopters and parcel deliveries by small Unmanned Aerial Systems (sUAS).

High-speed rotorcraft as tiltrotor or helicopters equipped with propulsive engines are at the horizon as well and will complete the VTOL offer with higher flight performances. Although they might occupy a smaller portion of the civilian rotorcraft market and will have higher operating costs than eVTOL vehicles, they could be of interest for applications where speed is a key factor for the success of the mission such as medical air transportation, law enforcement, some air taxis, and offshore services. AgustaWestland has developed the first tiltrotor civilian vehicle. Airbus[1] and Sikorsky[2] have flown demonstrators of high-speed helicopters.

Electric aircraft is a broad category of aerial vehicles that include fixed-wing aircraft powered by electric engines. Several prototypes have been flying and the first commuter aircraft retrofitted with an electric engine flew in December 2019[3]. Electric aircraft have promising applications for general aviation, commuter services and regional aviation. It might become a commercial reality during the 2020 decade. The feasibility of powering larger commercial aircraft with electric engines is not yet clearly established. Instead, larger aircraft might have hybrid propulsion systems electrically assisted during the cruise for lowering the consumption.[a]

Older and smaller single-aisle aircraft are being replaced by jets of more advanced design such as the Airbus A220, Embraer E-Jet E2, and Mitsubishi SpaceJet. These single-aisle aircraft are now being used for international services and open new opportunities for small and medium hub airports. The A321LR and XLR will soon be flying long-haul routes formerly reserved to middle-of-the-market 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.

The termination of the production of the A380-800 announced for 2021 is not the end of the Large Aircraft (LA). The Airbus A380 and Boeing 747-8 might still be operating commercial services at the 2040 horizon. The next generation of large and long aircraft is already here 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, at least 3 projects driven by U.S. start-ups have clean-sheet concepts for small supersonic jets either for commercial service (Boom Overture) or business aviation (Aerion AS2 and Spike S-512). While an entry into service (EIS) before 2025 as announced by these firms seem ambitious, demonstrators from Boom (Baby Boom XB1) and NASA (Lockheed X-59 Quiet SuperSonic Technology) should be flying as early as 2021. New standards will be needed to regulate the emissions and noise of these aircraft.[4] The comeback of civilian supersonic flight should not hinder the effort made by the industry to reduce the environmental footprint of aviation.

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[a] Airbus is developing the E-Fan X retrofitting a BAe 146 for demonstrating hybrid (electrically assisted) propulsion concepts.

A hypersonic civilian market could emerge at the 2070 horizon. The idea of using hypersonic aircraft, gliders, or rockets for providing very long-range mobility is not new and was first proposed at the end of World War II. The development of new technologies, materials and manufacturing processes could make them available to civil aviation for commercial services or corporate aviation. SpaceX has suggested that its reusable Starship under development could be used for flying intercontinental routes – such as New York City to Shanghai in less than 40 minutes.

Urban/Rural Air Mobility and the Future of Heliports

Urban Air Traffic Management (UATM)[5] and Unmanned Traffic Management (UTM)[6] concepts are being studied for allowing the safe operations of Unmanned Aerial Systems (UAS) – including beyond the visual line of sight (BVLOS) – and new VTOL aircraft. Allowing the operations of UAS beyond BVLOS will require these vehicles to broadcast their position in real-time to the remote pilot or station, operate within authorized airspaces, and ensure adequate separation with other users and obstacles. Part of the answer lies with remote identification – a key issue that the United States and the European Union try to address through rulemaking projects to expand the safe operations of UAS.[7,8] Specific provisions will be needed for enforcing geofencing at the proximity of airports[9], and the separation with manned aircraft within shared airspaces.[b] Options such as dedicated sUAS and air taxi corridors – similarly to existing helicopter routes in the denser urban areas or nearby aviation facilities – are under consideration as well. In a recent white paper, Embraer suggests that Urban Airspace Service Providers (UASP) should provide UATM in the lower airspace (below 1,000 ft. AGL) where appropriate.[10] The future of artificial intelligence for the control and command of these vehicles will require safe concepts of operations as well.[11]

Urban Air Mobility (UAM) is already a reality in some large metropolitan areas. 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 ensuring remarkable safety records. However, the noise and safety concerns have limited or reduced their operations over several cities (e.g., Paris, France; New York City, USA). New eVTOL aircraft promise to significantly reduce noise, enhance safety, increase availability[c], and reduce the cost of operations. Legacy manufacturers (Airbus, Bell, EmbraerX, etc.) and startups (e.g., KittyHawk, Volocopter) have developed over 60 concepts and a dozen of flying prototypes. Along with potential operators (e.g., Blade, Uber Air), they have created a thriving community in research and development[12,13]. To become a reality, they now need to establish safe and efficient concepts of operations, work with the regulators to translate them into regulations[d], and then find a viable business model out of these constraints. eVTOL will be physically piloted at first but might ultimately be remotely or automatically piloted (2040+ horizon).

Vertiports, vertipads, and vertistops are very similar to current heliports, helipads and helistops. Heliport design standards may need very little changes to be compatible with the new eVTOL vehicles. Besides the need for battery charging stations, providing an effective Mobility-as-a-Service (MaaS) solution will call for fast access from the ground to the elevated heliport, strategically located facilities to offer a competitive transportation network, and connecting the offer (eVTOL) to the demand (client). A new ecosystem of stakeholders and business models slightly different than the legacy helicopter service providers 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. Procedures and perhaps navigational aids shall be provided for flying instrument procedures in order to operate below the strict visual conditions. These requirements raise the question of the ownership and funding of the facilities. Revenues could be generated from the services offered to eVTOL

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[b] Small general aviation aircraft are less robust to collision with drones and might be more exposed to such accidents.

[c] Upon battery recharge cycles shorter or comparable to existing helicopter turnaround times.

[d] The EASA has ruled out that VTOL not fitting within existing aircraft and helicopter regulations should be certified under a Special Condition to these regulations.[d] The FAA has expressed a similar position without publishing specifics to date.

rotorcraft (e.g. facility charges, battery recharge) and their clients (e.g., amenities, lounges). It is also unclear if the vehicles will be owned and operated by the future aerial TNCs (e.g., Blade, Helifirst) or if they will connect the clients with certified operators (e.g., Helipass, Voom).

Airports already accommodate helicopter traffic and several of them even have heliport facilities. Helicopters typically account for a small percentage of the total operations, and with their unique flight performances their integration under these conditions is easily manageable even so VTOL are slow and generate significant wake turbulence compare to fixed-wing aircraft of similar weight[14]. If Urban Air Mobility blooms and is used to serve airports with a high frequency (several times per hour) at the peak hour, provisions shall be taken to preserve airside capacity for the existing users and accommodate this new VTOL traffic as well. A way to achieve this taking is to separate the latter from the general fixed-wing traffic with a heliport facility away from the runways. It should be equipped with adequate flight procedures not conflicting with those of the runways and helicopter routes channeling the VTOL traffic. Similar considerations should be given to small UAS operations from regional freight distribution centers based at airports with UAS corridors vertically and/or horizontally separated from the aircraft traffic.

Aircraft Configuration & Airport Compatibility

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 aspects of airport compatibility, such as the length or pavement stress. The 777-9 is the longest commercial aircraft ever, and a longer version has even been considered (777-10X). There is an upward trend in the tire pressure of aircraft – meaning that the weight is getting concentrated on a smaller area. Large aircraft are also popular in the air cargo business as they can move extra-large payloads or support busy routes (777F, 747-8F, An 124). Domestic facilities also see similar trends with longer and heavier single-aisle aircraft for serving existing routes. Issues with aircraft compatibility are a reality for airports of all sizes, from large hub airports to smaller facilities serving remote communities. They can have an impact on air service development, certification, lifespan and maintenance cost of existing pavement, and capital expenditure for adapting the infrastructure and equipment or reconstructing for more demanding aircraft.

The emergence of the New Large and Long Aircraft (NLA) in the years 1990 and 2000 – the Airbus A340-600 and A380-800, and the Boeing 777-300/-300ER and 747-8 – compelled airports, airlines aircraft manufacturers, and regulators to work together for fitting these aircraft at existing airports. They conducted research in airport engineering and found consensus for safely accommodating them at aviation facilities that were not designed for them per the standard then in force. Specific industry documents have been issued for the Airbus A380-800[15], Boeing 747-8[16] and Boeing 777-8/-9[17]. Moreover, this approach led to the rise 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 Convention of Chicago that reviewed all airport design criteria, identified their safety objectives, associated levels of safety, and from there refined them based on rationales and statistical studies. Today, mature methodologies and models exist to support aeronautical studies requesting local modifications of standards on runway width[18,19], runway strip and runway end safety area[20], ILS protection areas[21], taxiways, etc. Airports have learned to develop their own technical policies as well[22] based on ICAO-approved approaches[23].

The traffic area is also concerned by airport/aircraft compatibility.[e] At the short- and medium-term horizons, airports will have to continue adapting their ramp infrastructure to fit new airframes of different shapes with potential issues in terms of aircraft stand depth, fuel pit location, and jetbridge compatibility. Electric aircraft or hybrid propulsion systems for larger aircraft might require airports to install powerful charging stations at the gate – similarly to the move to built-in 400Hz blocks in lieu of GPU. In the meantime, ground service equipment (GSE) are also turning electric. As of today, virtually all the

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[e] On the non-movement area in the United States.

GSE vehicles have electric counterparts in the catalog of the main manufacturers – including tow-tractors. These vehicles need charging stations as well, increasing the power demand. Another change to come is the introduction of green taxiing technologies. Two technologies are in competition: built-in electric engines on or incorporated in the landing gear (e.g. Wheeltug, EGTS), and external equipment towing the aircraft from the gate to the threshold (e.g. TaxiBOT at FRA and DEL). The success of such equipment is for now driven by the price of the kerosene. However, the long-term increase in fuel price, the social pressure to get greener, and technical progress (e.g. reversible electric brakes) might make green taxiing more accessible in the near future. They need concept of operations and procedures that minimize their impact on airport operations and facilities.

A revolution in aircraft design configuration has yet to come. 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 explored by research centers and aircraft manufacturers – some of them under publicly funded initiative (e.g., EU Clean Sky[24], NASA Advanced Air Vehicles Program) to pave the way to the next generation of airliners that will replace the Airbus A320 and Boeing 737 families. These innovative features aim at reducing consumption and noise, but they can be challenging from an aircraft compatibility perspective. As the aviation community already explored these issues with the NLA, an aircraft program cannot be successful if it requires excessive adaptations of the existing airport infrastructure. The progress of structural design and manufacturing process enables the introduction of innovations that will facilitate their integration at existing airports, such as the Folding Wingtips (FWT) on the Boeing 777-8/-9. More generally, they shall be operations-friendly from the landside to the airspace as airport compatibility is not only about airfield engineering, but shall embrace and address airspace operations, airport terminal design, and operations, and noise and emissions aspects as well.

Becoming Gateways Toward the Sound Barrier and the Kármán Line

Future supersonic aircraft will have different approach speeds than conventional aircraft. The experience of Concorde and military-civilian joint-use facilities show that it is possible to have these aircraft coexisting together. However, it does have an impact on the capacity to have aircraft with different flight performance. Also, they will have longer runway length requirements compared to subsonic aircraft which might limit the options of supersonic business jets for operating from secondary airports. Supersonic aircraft are longer compared to subsonic aircraft of similar passenger capacity. Finally, the new generation of supersonic aircraft will have to minimize their noise and emission to at least not exceed those of existing subsonic airliners.[f]

Commercial aircraft already share the airspace with spacecraft worldwide. The diversion of commercial flights for avoiding large aviation hazard areas (AHA) of several hours posed by spacecraft launches and reentries causes significant delays occasionally. The growth of commercial space transportation with new spaceports and spacecraft operators will require to rethink this cohabitation that will even occur at airports. There are currently 11 licensed spaceports in the United States[25] that has a comprehensive regulatory framework for launch[26] and reentry[27] 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 (CFO), is situated at less than 5 NM from Denver Intl. Airport (DEN). The U.S. FAA is developing new tools for a more dynamic allocation of airspaces such as the Space Data Integrator (SDI). ADS-B is being tested on rockets. The emerging Space Traffic Management (STM) will have to interface with Air Traffic Management (ATM). 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

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[f] Ongoing U.S. projects typically target a ground noise lower than 75 EPN dB. They will most likely comply with ICAO Annex 16, Volume 1 Chapter 4 standards or U.S. 14 CFR Part 36 Stage 4 without achieving Chapter 5/Stage 5.

and spaceport operations. The next spaceport to open might be Spaceport Cornwall at Cornwall Airport Newquay (NQY) with Virgin Orbit operating a specially modified Boeing 747-400 as carrier vehicle.

Integrating New Energy Vectors at Airports

The main families of aviation fuel are currently the jet fuels (e.g. Jet A1) for turbo-engines, and the avgas (e.g., 100LL) for piston-engines. Sustainable Aviation Fuels (SAF) or "Alternative Fuels" are produced from sources such as biomass or waste and then mixed with fossil fuels under current standards. Aviation-certified SAF contains up to 50% of synthetic fuel. They are certified as Jet A1 and can fuel existing aircraft without technical modification. They can be delivered via existing hydrant systems or trucks. Commercial service airports delivering SAF at large-scale include Los Angeles (LAX), Oslo (OSL), Bergen (BGO), and Stockholm (ARN). The Port of Seattle has set a goal to power every flight refueled at SEA with at least a 10% SAF blend by 2028.

Electric aircraft are a more radical move away from fossil fuels. In addition to reducing emissions, this technology can dramatically reduce noise. At the 2040 horizon, we can expect most of the small aircraft (general aviation and commuters) and VTOL aircraft (UAM/RAM) to be electrical, and new larger aircraft to be powered by hybrid systems. Transitioning to electricity will require airports and their stakeholders to invest in charging stations and adapt their power supply – which could be a push for local production (e.g., solar farms) and microgrids. To keep e-aircraft competitive, battery charging should not adversely impact the turnaround time. Either the batteries should be able to stand a day of operation and be recharged overnight, or they should be replaced at the gate. Transitioning to electric aviation will also challenge the business model of the fixed-base operators (FBO) and aviation fueling service providers.

Hydrogen (H_2) has been tested on aircraft prototypes and ground service equipment (GSE). However, powering large fleets of e-aircraft, hydrogen aircraft, and eGSE on H_2 would require new logistics and distribution infrastructures that do not exist today or are not yet adapted to such demand.

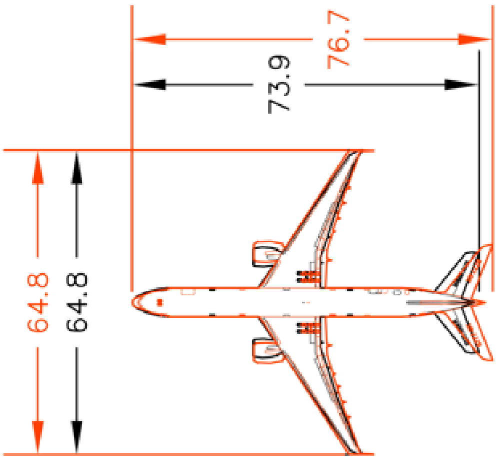
Emerging Stakeholders and Their Impact on Compatibility

The capacity of an airport to accommodate new types of aircraft in a safe and efficient way also lies in the level of cooperation between the stakeholders. While the civil aviation community has reached a certain maturity and 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. The previous example on Urban Air Mobility listed several players that do not yet exist. The rise of electric aircraft will challenge the business model of the aircraft fueling service providers and many fixed-base operators.

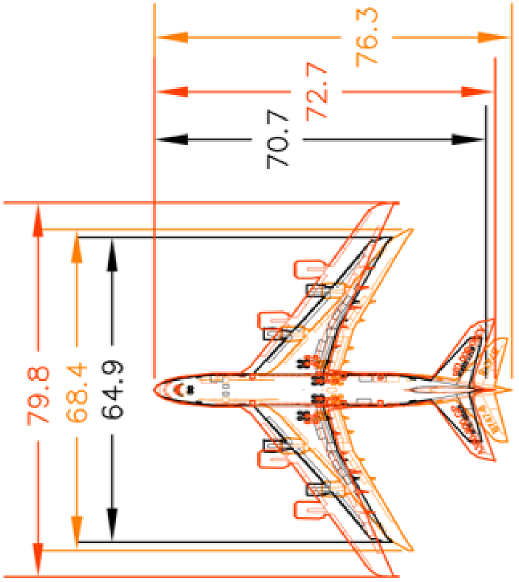
What if airlines themselves break between flight operators providing ready aircraft and holding the air operator certificate, and mobility providers developing the commercial offer and selling tickets? These charters of a new genre could both help to leverage growth in booming regions where flight operators 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. Agreements between the parties of these "compound airlines" that could easily be recomposed and adapt to the evolutions of the demand could be facilitated by a new generation of contracts and certificates powered by blockchain technologies.

Airport operators also evolve and adopt more complex profiles. We now find public operators, private operators, and more complex models where, for instance, the airport is publicly owned, but all the terminal facilities are operated by separate private entities competing for airlines (e.g., JFK).

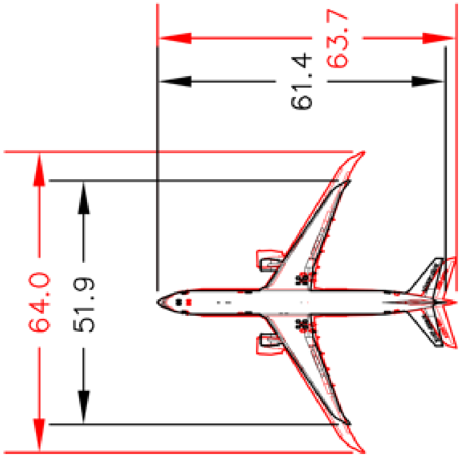
Appendix 6-1 - Comparisons Between Legacy Airliners and Their Successors



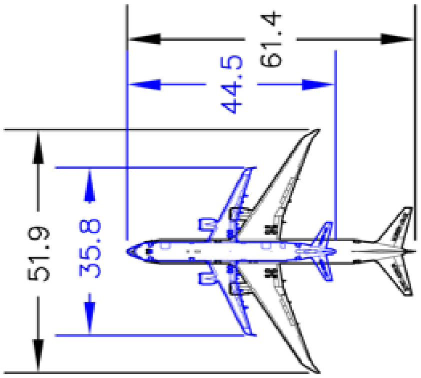
B777-300ER vs B777-9X



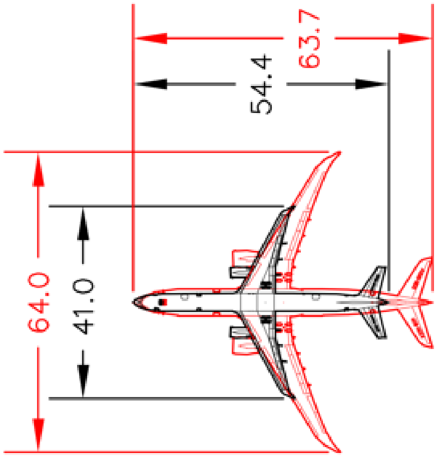
B747-400ER vs B747-8 vs A380-800



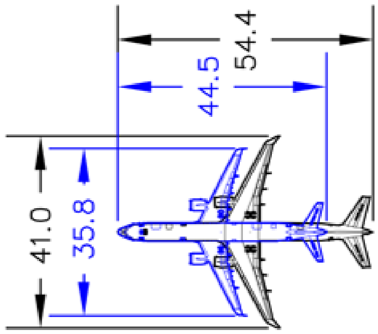
A330-900 vs B767-400ER



A321NEO vs B767-400ER



A330-900 vs B757-300W



A321NEO vs B757-300W

Appendix 6-2 - Aircraft Characteristics for Airport Planning

Table A6-1 – Characteristics of a Selection of Airliners at the 2025 Horizon

Manufacturer	Airbus	Airbus	Boeing	Embraer	Mitsubishi
Type	A220-300	A321XLR[2]	777-9[3]	E195-E2	M100
Expected EIS	2020	2023	2021-2022	2019	2023
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 76.7 m[2,3] (213 ft. x 252 ft.)	35.1 m x 41.5 m (115 ft. x 136 ft.)	27.8 m x 34.5 m (91.3 ft. x 113 ft.)
Engines	2	2	2	2	2
Seats	120-150	200-244	349-426	120-146	76-84
Max. Range	3,350 NM 6,200 km	4,700 NM 8,700 km	7,300 NM 13,500 km	2,600 NM 4,800 km	1,900 NM 3,550 km
Runway Length Requirement[1]	2,743 m (9,000 ft.)	2,811 m (9,222 ft.)	3,048 m (10,000 ft.)	1,750 m (5,141 ft.)	1,760 m (5,770 ft.)

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.

3 – The runway length requirement was computed based on the data released for the 777-300ER based on Boeing's recommendations.

3 – 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.).

4 – A proposed lengthened version (777-10X) had a length of 80 m (263 ft.).

Table A6-2 – Comparison Between Concorde and Proposed Future Supersonic Aircraft

Manufacturer	Aérospatiale/BAC	Aerion	Spike	Boom Technology
Type	Concorde	AS2	S-512	Overture
Market Segment	Commercial Service	Business Aviation	Business Aviation	Commercial Service
Expected EIS	1976	2025	2023	2025-2027
Wingspan x Length	25.6 m x 61.7 m	23 m x 52 m	17.7 m x 37 m	18 m x 52 m
Cruise Speed	2.04	1.4	1.6	2.2
Engines	4	3	2	3
Passengers	92-128	8-11	18	45-55
Max. Range w/ Supersonic Cruise	3,900 NM 7,223 km	4,200 NM 7,780 km	6,200 NM 11,482 km	4,500 NM 8,300 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
Airport Compatibility Features	None	Non-afterburning engines	"Boomless" technology	Non-afterburning engines
Unit Cost	160 MUSD	120 MUSD	60-100 MUSD	200 MUSD
Clients	Air France British Airways	Flexjet	–	Virgin Group Japan Airlines

**** Takeoff requirement assuming MTOW, ISA, Sea Level.***

Table A6-3 – Concepts of 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	In Development	In Development
Type of Flight	Atmospheric	Atmospheric	Suborbital	Suborbital
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
Engines	4 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.***

Table A6-4 – Selection of Existing and Proposed Rotorcraft

Manufacturer	AgustaWestland	Bell	Volocopter	Boeing/AFS	Airbus
Type	AW609	Nexus	2X	PAV	CityAirbus
Configuration	Tiltrotor	Tiltrotor	18-Axis/-Rotor	Compound	4-Axis / 8-Rotor
Missions	Multirole	UAM/RAM	UAM/RAM	General Aviation	UAM/RAM
First Flight	2003	<2025?	2013	2019	2019
Overall Length	13.4 m (44.0 ft.)	12 m (40 ft.)	9.15 m (30.0 ft.)	–	–
Rotor Diameter or Overall Width	17.9 m (58.7 ft.)	12 m (40 ft.)	9.15 m (30.0 ft.)	–	–
Engines	2 turboshafts	6 hybrid engines	18 electric engines	1 + 8 electric	8 electric engines
Passengers	6-9	5	1	2-4	4
Max. Range	750 NM	130 NM	17 NM	47 NM	50+ NM

Table A6-5 – Innovative Aircraft Features and Their Impact on Airport Compatibility

Design Feature	Comments on Airfield 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
Blended Wing	- Aircraft evacuation concepts to be developed. Existing bridge compatibility? - 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 Boeing BWB
Boxed-Wing	- Smaller wingspan than comparable turbojets. - Opportunity for engines mounted on upper wing.	NASA/Lockheed
Folding Wingtips	- Significantly increase compatibility with existing airport infrastructure. - Requires airport-friendly CONOPS (see BACG2).	Boeing 777-8/-9

Table A6-7 – Selected Spacecraft Characteristics

Spacecraft Manufacturer	Northrop Grumman IS	The Spaceship Company	SNC Space Systems	Blue Origin	SpaceX
Spacecraft Model	L-1011 Stargazer/ Pegasus XL	WhiteKnight/ Spaceship Two	Dream Chaser	New Shephard	Spaceship
Spacecraft Operator	Northrop Grumman IS	Virgin Galactic	NASA	Blue Origin	SpaceX
Status	In service	Flight tests	In development	In service*	In development
Mission	Small satellites	Suborbital flights	ISS resupply (manned or cargo)	Suborbital flights	Heavy orbital multi-missions
Dimensions	See L-1011	43 m x 24 m (141 ft. x 79 ft.)	(23 ft. x 30 ft.)	7 m x 18 m (23 ft. x 56 ft.)	9 m x 118 m (30 ft. x 387 ft.)
Launch	Under L-1011	Under WK2	ULA Vulcan	Vertical	TSTO
Reentry	N/A	Glided Reentry	Glided Reentry	Vertical	

**** Scientific and commercial payloads only. Will ultimately provide manned flights.***

Abbreviations

AAVP	Advanced Air Vehicles Program
A-CDM	Airport Collaborative Decision Making
ACRP	Airport Cooperative Research Program
AFIS	Aerodrome Flight Information Service
AHA	Aviation Hazard Areas
AI	Artificial Intelligence
ANN	Artificial Neural Network
APOC	Airport Operations Center
ARIWS	Autonomous Runway Incursion Warning System
ATL	Hartsfield-Jackson Atlanta International Airport
ATM	Air Traffic Management
BVLOS	Beyond the Visual Line of Sight
CDG	Paris-Charles de Gaulle Airport
CDM	Collaborative Decision Making
CNS	Communication, Navigation and Surveillance
DFW	Dallas-Fort Worth International Airport
EASA	European Aviation Safety Agency
ENAC	Ecole Nationale de l’Aviation Civile
ENANA-EP	Empresa Nacional de Exploração de Aeroportos e Navegação Aérea E.P.
ERAU	Embry-Riddle Aeronautical University
EU	European Union
FAA	Federal Aviation Administration
FIT	Florida Institute of Technology
GANP	Global Air Navigation Plan
GASeP	Global Aviation Security Plan
GASP	Global Aviation Safety Plan
GMF	Global Market Forecast
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
IST	Istanbul Airport
KUL	Kuala Lumpur International Airport
LAC	Latin American and Caribbean
LAWA	Los Angeles Airport World
LGP	LaGuardia Gateway Partners
LHR	London-Heathrow
MDAD	Miami-Dade Aviation Department
MIA	Miami International Airport
ML	Machine Learning
MRS	Marseille-Provence International Airport
MWAA	Metropolitan Washington Airports Authority
NASA	National Aeronautics and Space Administration
NEXTT	New Experience Travel Technologies
NFC	Near-Field Communication
O&C	Ownership & Control

OCC	Operations Control Center
OER	Örnsköldsvik Airport
ONDA	Office National Des Aéroports
ORD	Chicago-O’Hare International Airport
ORY	Paris-Orly International Airport
PPP	Public-Private Partnership
PPP	Purchasing Power Parity
PKX	Beijing Daxing International Airport
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
SAF	Sustainable Aviation Fuels
SAT	San Antonio International Airport
SARP	Standards and Recommended Practices
SDI	Space Data Integrator
SDL	Sundsvall–Timrå Airport
SFB	Orlando Sanford International Airport
SIIED	Surgically Implanted Improvised Explosive Device
SIN	Singapore-Changi International Airport
SJU	San Juan Luis Muñoz Marín International Airport
SMS	Safety Management System
SWIM	System Wide Information Management
TAM	Total Airport Management
TIP	Tripoli International Airport
TNC	Transportation Network Companies
TOSC	Technical, Operations & Safety Committee
TRB	Transportation Research Board
TRT	Turnaround Time
UAM	Urban Air Mobility
UATM	Urban Air Traffic Management
USOAP	Universal Safety Oversight Audit Programme
UTM	Unmanned Traffic Management

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