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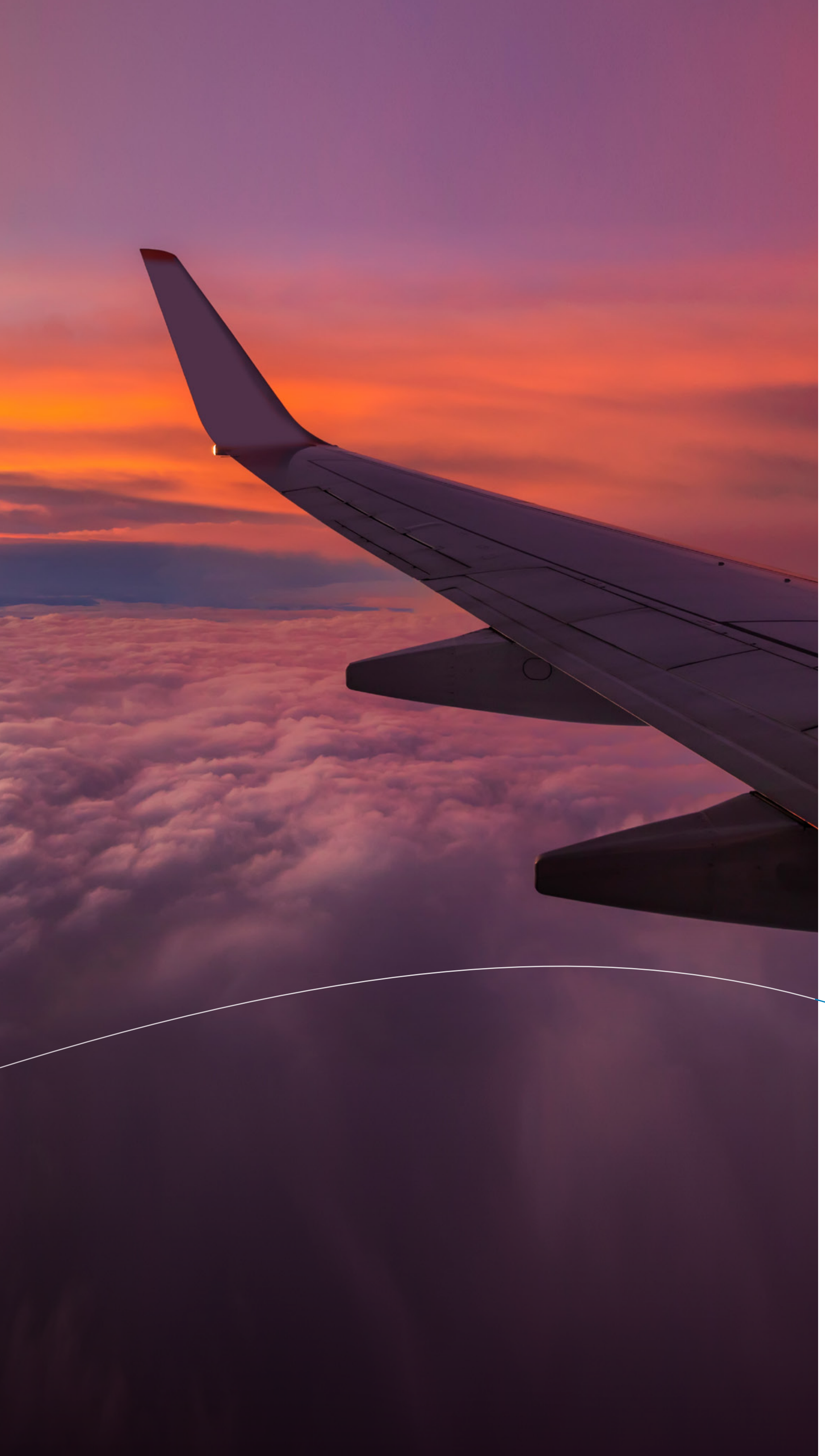
Cranfield University

DIGITAL NOW:

WHY THE FUTURE OF AVIATION STARTS WITH CONNECTIVITY

Executive Summary

Presented in partnership between Inmarsat and Cranfield University



The pandemic's impact has been felt across all parts of society – not least in the global aviation sector. In addition, the increased awareness of the impact of climate change caused by human behaviour, including transport, has helped create a "perfect storm" that is causing the sector's key industry stakeholders, its customers, and governments across the globe to fundamentally reconsider their priorities and the sector's future service offering. What is clear, as never before, is that while there is consensus for change, the pace and direction still remains uncertain.

This paper by Cranfield University, sponsored by Inmarsat, has considered how the role of Digital Connectivity, in all its forms, can enable and accelerate the rapidly changing needs of air travellers and of the aviation sector itself. It has identified specific challenges and opportunities that, if addressed, will have a direct effect on the sector's resilience, its contribution to reducing climate change, and to new customer service offerings that will enhance passengers' willingness to travel in the post-pandemic world.

The outcome of the paper is a **Digital Connectivity Timeline**, outlining adoption timelines for the technologies that will – in time – define the future of Aviation.

- **Within 5 years** – Technologies and systems that are at advanced stages of development and in some cases are being piloted by organisations ahead of market adoption
- **5 to 10 years** – Technologies and systems that are under early development and have the potential to be trialled in some sectors
- **Beyond 10 years** – Technology concepts that are under consideration for product or service offering development

1 DRIVERS OF ACCELERATING CHANGE

The pandemic has shifted the behaviour of key stakeholders in the aviation sector. Customers, governments, and the airlines themselves are reconsidering their priorities and the sector's future service offering. In some instances, the pandemic has helped accelerate efforts towards a more efficient and secure airspace that is fit for the future, but most of all it has created a new stronger focus on the sector's use of **digital data**.

Whether considering climate change, system design and reliability or economic resilience, the acquisition of new and higher quality data from across the entire sector will be increasingly important for building a sustainable future for the aviation industry.

Data will be needed for anticipating risks and ensuring there is greater cross-sector flexibility to deal with them; for testing the alternative technologies needed for a sustainable aviation business; to develop new kinds of shared frameworks, systems and technologies; and for improving and ensuring cybersecurity.

2 THE AVIATION ECOSYSTEM AND TIME HORIZONS

Conventional definitions of ‘aviation’ and ‘aerospace’ understandably are centred on the aircraft[1,2,3], however they tell us nothing about the structure and complexity of the aviation industry and only hint at its considerable breadth. Most importantly, these definitions highlight an attitude that appears to limit the essential vision for development.

Instead, we must focus on the benefits of technologies to the sector’s ultimate customer – the **Airline Passenger**. Firstly, the paper considers the **Aircraft** and the connectivity opportunities and challenges associated with its ability to exchange and use ever-increasing amounts of data – including the Conscious Aircraft as a concept that might define how an aircraft of the future might have a heightened awareness of itself.

Then it considers the **Airlines** and the role of connectivity in providing new and enhanced services to an industry that has been on the receiving end of the COVID-19 pandemic, and is having to redefine its business models, whether it operates in short-haul or long-haul markets.

The role of the satellite communications industry in the shaping of future **Airspace** connectivity is discussed with particular emphasis on key drivers such as entertainment/broadcasting services and future UAS communications services.

Airports are considered by some as being at the centre of an aviation communications infrastructure – so the core digital needs of the airport are therefore reliable, simple to access common data communications platforms that are able to handle all forms of data securely and swiftly.

Finally, the paper focuses on the role of **Artificial Intelligence** in aviation, a simple introduction to some of the many applications AI is finding within aviation and provides examples of what is and will be being developed in the very near future.

[1]Oxford Languages: “the flying or operating of aircraft”
[2]Cambridge Dictionary: “the activity of flying aircraft or of designing, producing and keeping them in good condition”
[3]www.askdifference.com/aerospace-vs-aviation: “engineering effort to fly in the atmosphere of Earth (aeronautics) and surrounding space (astronautics)”

3 THE AIRCRAFT: CONNECTIVITY AND CONSCIOUSNESS

New aircraft-based technologies and standards are giving rise to both the ‘Connected Aircraft’ and the ‘Connected Cockpit’. These are connected-anywhere concepts that have fully connected digital ecosystems enabled by multiple data links, and feature secure, high-bandwidth satellite connectivity alongside a combination of radio and internet streaming. The complexity and interoperability of future ecosystems is seen as significant challenge for technology providers, regulators, and airlines alike.

THE CONSCIOUS AIRCRAFT

It goes on to discuss the ‘conscious’ aircraft. In practice, can an aircraft be ‘conscious’? The strict answer is no – because consciousness is more than awareness: it is the awareness of awareness. An aircraft, however, can be ‘conscious’ in ways that are important to improving aircraft health, maintenance, and performance. The Conscious Aircraft initiative aims to achieve the creation of an integrated vehicle health management system that is capable of a fully aware state, able to either suggest appropriate action or take action for itself.

The Conscious Aircraft of the future monitors current platform health, reliably predicting the remaining useful life of components and systems and then automatically reconfiguring them to optimise their remaining life. This means technology that senses every aspect of an aircraft’s engineering, connected with a human-like nervous system, and also has a skin – is able to sense changes in the external environment, like weather or smoke from an ash cloud.

Such a capability will have a major impact on operational efficiency, facilitating more sustainable fleet operations and supporting the introduction of new technologies aimed at reducing emissions and environmental impact. The Conscious Aircraft principle uses sensing and communication technologies to increase awareness that removes risk and unnecessary costs: avoiding problems caused by component degradation, unpredicted technical failures and human error. With the reduced need for routine, planned maintenance, as well as anticipating the potential for failures with a Conscious Aircraft, maintenance costs would be cut by an estimated 30%[4].

[4] Oliver Wyman, Global Fleet and Market Forecast 2020-2030, 11 February, 2020.

4 AIRLINE OPERATIONS – RECOVERING FROM THE PANDEMIC AND BEYOND

We know that air travel needs to be safe, workable, and convenient – and most of all, airlines and airports, with their supply chains and collaborators, will need to be able to adapt rapidly to changing market needs. Airlines in particular will need to be more flexible and agile than they have been in the past if they are to survive inevitable new shocks.

Enhanced digital connectivity is enabling the concept of a "connected journey", through creating more efficient and personalised wayfinding through airports, more intelligent and responsive baggage tracking, and real-time updates on the condition and progress of cargo in transit. Passengers are, however, requesting that they are better informed of unavoidable weather-related disruptions – and that alternative, personalised travel arrangements are made available to them in a timely and digital manner.

Inflight, passengers and crew now expect the same levels of personal digital connectivity as they experience in their everyday lives. Digital inflight entertainment (IFE) services, for example, that were once only provided by the premium long-haul carriers, are now having to be considered by low-cost carriers. Providing seamless connectivity to passengers' own tablet and smartphones ("bring your own") is seen as a means of avoiding costly and heavy aircraft upgrades, and potentially introducing new IFE service revenue streams through subscription or third-party advertising for the low-cost carriers.

Beyond IFE, new digital services could support a greater sensing of individual passenger wellbeing (e.g. anxiety levels) and service satisfaction, provide individual onward travel information, and support onboard virtual queueing for toilets and meal distribution. The overall effect would be to provide an enhanced and, most importantly, personal inflight service. Various options to monetise passenger connectivity services are being considered and will be essential to defray additional launch and operational costs.

5 AIRSPACE OPERATIONS NEW CHALLENGES AND NEW OPPORTUNITIES

Prior to the onset of the COVID-19 pandemic, the pressures of global airspace congestion were already being seen and felt. Average delays, both on departure and arrivals, reached 20 minutes per flight in peak summer months and 10 minutes in winter[5]. The so-called 'capacity crunch' affects both airports and the wider network. Without transformative action, airports were expected to be unable to accommodate the forecast 1.5 million daily flights in 2040, equivalent to around 160 million passengers being unable to fly[6].

The management of post COVID-19 future air traffic growth – which will also likely include entirely new flight systems and mitigate environmental impacts – will be dependent on transformation of the existing air traffic management system. This includes the airspace regulatory structures themselves, through the increased adoption of automation. A priority focus on Trajectory Based Operations is seen as a critical step towards the future management of existing air traffic, to allow more efficient traffic sequencing and routine deployment of so-called fuel efficient "green descents" to airport terminal areas.

[5]https://www.eurocontrol.int/sites/default/files/2020-06/eurocontrol-prr-2019.pdf
[6]https://www.sesarju.eu/masterplan2020

6 THE FUTURE OF AIRPORT CONNECTIVITY

Airports are at the centre of an aviation communications infrastructure, handling large quantities of time sensitive data to manage local aircraft movement – plus directly benefiting the efficient movement of passengers, their baggage, and transiting cargo.

Digital infrastructures are being developed to create more efficient wayfinding for passengers through the airport, more intelligent and responsive baggage tracking, and real-time updates on the condition and progress of cargo in transit.

The management of aircraft movements is core to an airport's operation. Multiple ground-based wireless sensor systems (such as VHF data links), generating operational data to the airport's ground control centre provide improved surface operations, low visibility operations, collaborative ATM, performance-based navigation and improved weather and navigation information. The rapid growth of piecemeal technologies, however, has led to data noise caused by a mix of new, legacy and obsolete technologies. This has created latency, reliability, and scalability concerns.

Airports of the future will increasingly rely on forms of ultra-reliable, low-latency 5G provision. The advantage of 5G lies in the provision of very high data rates, extremely low latency, and an increase in base station capacity. Satellite enabled provision linked with cellular and terrestrial networks, despite an initial infrastructure cost challenge, will give service providers the flexibility to make choices and use combinations of satellite, terrestrial and mobile networks to ensure a consistent and reliable service for users globally.

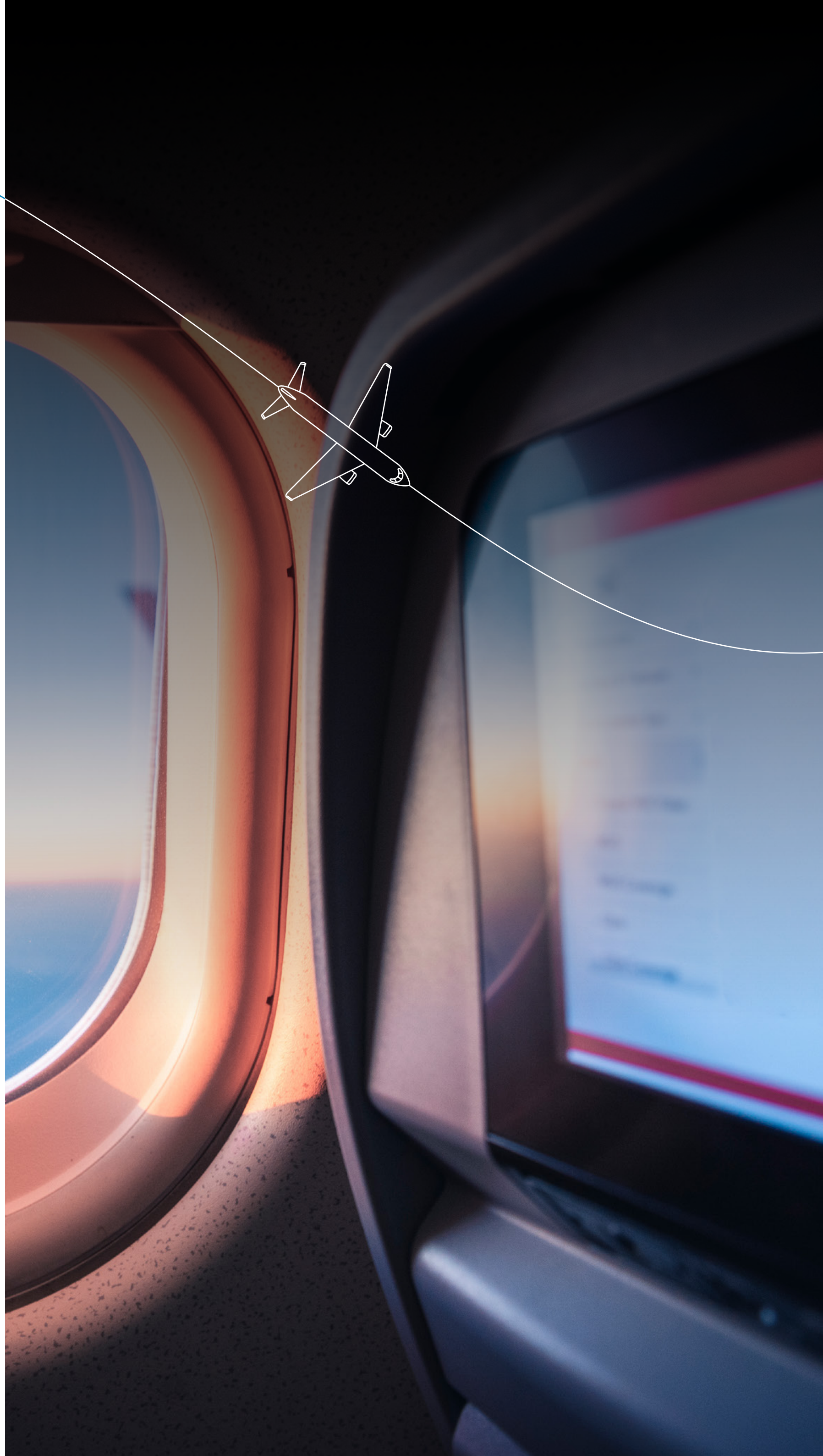
7 ARTIFICIAL INTELLIGENCE AND DIGITAL TRUST TECHNOLOGIES; UNDERPINNING THE PASSENGER EXPERIENCE

Artificial intelligence (AI) and digital trust technologies have enormous potential for being applied across all aviation sectors, impacting on passenger experience in all forms.

Deep neural networks, built on big data, cloud computing, computer-based vision, the IoT and graphics processors, have narrowed the gap between the science and real-world applications. AI can provide intelligent advice on aircraft management issues and make informed decisions under pressure – when there is the need to make a diversion, for example – with camera-based traffic detection, or helping crew to anticipate and prevent critical situations. Machine Learning (ML) should improve accuracy of any application involving optimisation, from sensor calibration to fuel tank checks to icing detection[7].

AI will also be the foundation for creating future solutions to complex challenges, such as the demand for urban air mobility in the world's congested cities. Unmanned aircraft will be reliant on systems able to make complex decisions to ensure safe flight and landing; for example, managing the separation between air vehicles based on reduced distances, compared with conventional air traffic management practices.

This is where AI makes the difference in delivering full autonomy – the powerful algorithms deal with huge amounts of data generated by embedded sensors and by machine-to-machine communications. There are still no benchmark cases of large-scale applications in the aviation industry, and there are major question marks over trust in AI and its ability to make ethical decisions. The planning, construction, maintenance, and optimisation processes of AI and communications networks will need to be gradually combined.



[7]https://www.easa.europa.eu/sites/default/files/dfu/EASA-AI-Roadmap-v1.0.pdf

DIGITAL AVIATION ROADMAP

WITHIN 5 YEARS

Health and Wellbeing
Enhanced onboard sanitation using UV-C cleaning of cabin surfaces, and widespread adoption of digital health passports.

Travel Personalisation
Real-time travel information and personalised wayfinding using computer vision techniques, supported by tailored commercial offerings to enhance journey experience.

Passenger Travel Security
Adoption of early biometric monitoring for increased airport security.

Onboard Passenger Digital Experience
5G streaming of digital media content to personal devices, offering new e-commerce and entertainment opportunities to the airlines and operators.

Uncrewed Traffic Management
Initial Beyond Visual Line of Sight (BVLOS) operational frameworks with operator enabled configuration and control through virtualisation and satellite communication elements via 5G network integration.

ATS Management
Increased ATM operational capacity through reduced dependence on ATC voice commands (via satcom enabled data link services), next-generation multi-channel programmable software-defined VHF radio and remote provision of Air Traffic Services (ATS).

Airline Asset Management
Application of big data principles, predictive analytics and machine learning for enhanced airline asset management through fleet operational optimisation and human resource planning.

Aircraft Data Management
Improved flight and aircraft data management through the deployment of Electronic Flight Bag services, inflight transmission of aircraft maintenance data and aircraft predictive maintenance scheduling.

Airspace Information Harmonisation
Initial framework design and services from ICAO's System Wide Information Management (SWIM) initiative within the Global Air Navigation Plan (GANP).

Trajectory-Based Operations (TBO) and Green Descents
Initial 4D deployment and Single European Sky Imaging through initial technology and multilink interface designs that include satellite communications and L-Band Digital Aeronautical Communication systems (LDACS).

Airport Multi Stakeholder Interoperability
Enhanced multi-vendor airport terminal and hub interoperability through providing seamless system of system (SoS) interface characterised by technical specifications including architecture, protocol stack and radio access levels.

DIGITAL AVIATION ROADMAP

5 TO 10 YEARS

Health and Wellbeing
Smart cabin environments sensing passenger temperature, anxiety and hydration levels, enabling enhanced comfort management by crew and resulting in increased customer satisfaction and crew work experience.

Passenger Travel Security
Walk-through security screening using AI enhanced 3D scanning approaches with material discrimination, high rates of detection and low levels of false alarms, providing both increased security and uninterrupted passenger airport movement.

Passenger Travel Security
Adoption of identity recognition technology in combination with behaviour analysis to identify abnormal passenger behaviour within airport terminals, creating a safer environment.

Data Communication Integration
Seamless digital communications mobility using heterogenous and integrated technology environments (LTE, 4G, 5G, Satellite, LDACS) to provide greater communications resilience and capacity for both existing and future flight (UAV) systems.

Airspace Information Harmonisation
Full System Wide Information Management (SWIM) implementation, enhancing global airspace information exchange and airspace utilisation.

Inflight Data Capacity
Implementation of Artificial Intelligence to provide inflight bandwidth selection optimisation for greater data capacity and resilience.

Future Flight Airspace Integration
eVTOL Aircraft airspace integration can be via digital-data exchanges, such as Controller Pilot Data Link Communications (CPDLC) or System Wide Information Exchange (SWIM) protocols.

Communications Infrastructures
New communication infrastructures are expected to be deployed, using Digital Terrestrial Transmission (DTT) and Satellite Hybrid Wireless Mesh Networks to improve backhaul networks and virtual network operators.

Trajectory Flight Optimisation (TBO)
Advanced deployment with full integration of flight information and synchronised view of flight data by all actors involved, providing enhanced airspace capacity and reduced fuel burn.

Airspace Surveillance
Global satellite-based digital data links enabling Automatic Dependent Surveillance Contract (ADS-C), Extended Projected Profile (EPP) downlinks airspace surveillance performance.

Uncrewed Traffic Management
Regulatory framework for advanced BVLOS operations enabling commercial cargo, B2B drone operations and initial passenger air taxis services.

Aircraft Data Management
Advanced aircraft digital data capture approaching 100 billion gigabytes per year, enabling widespread sector adoption of predictive maintenance scheduling that will reduce aircraft downtime.

Aircraft Data Management
Whole aircraft digital twin representation fully enabled through aircraft sensor data and launch of prototype self-aware and self-reasoning aircraft having “consciousness”.

DIGITAL AVIATION ROADMAP

BEYOND 10 YEARS

Data Communication Integration
Deployment of intelligent IoT networks (e.g. mesh) and virtual network operators, providing air-to-ground and air-to-air connectivity integration.

Communications Infrastructures
Application of 6G core network-based AI, cloud edge computing and use of quantum encoding to manage data privacy and authentication.

Airspace Management
Virtual centres associated with sector-independent ATS enabling dynamic, optimised and shared management of airspace.

Airspace Management
Service-based approach to surveillance and communications infrastructure.

Aircraft Maintenance
Remote inflight or ground based aircraft servicing and emergence of pilot led maintenance support using VR/AR seamless communication between maintenance engineers and aircraft self-awareness (consciousness).

Aircraft Data Management
In service “conscious” aircraft and emergence of “zero maintenance” platforms.

Uncrewed Traffic Management
Regulatory framework for routine BVLOS operations in all environments (including urban) enabling B2B and B2C drone and UAM taxi services.

Trajectory Based Operations (TBO)
Full 4D deployment enabling ATS to adopt a supervisory service.

Aircraft Maintenance
Prototype “lights out” automated MRO hangars that are activated on demand.

CONTACT

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DIGITAL NOW:

WHY THE FUTURE OF AVIATION STARTS WITH CONNECTIVITY

Full Report

Presented in partnership between
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FOREWORD

Philippe Carette,
President,
Inmarsat Aviation

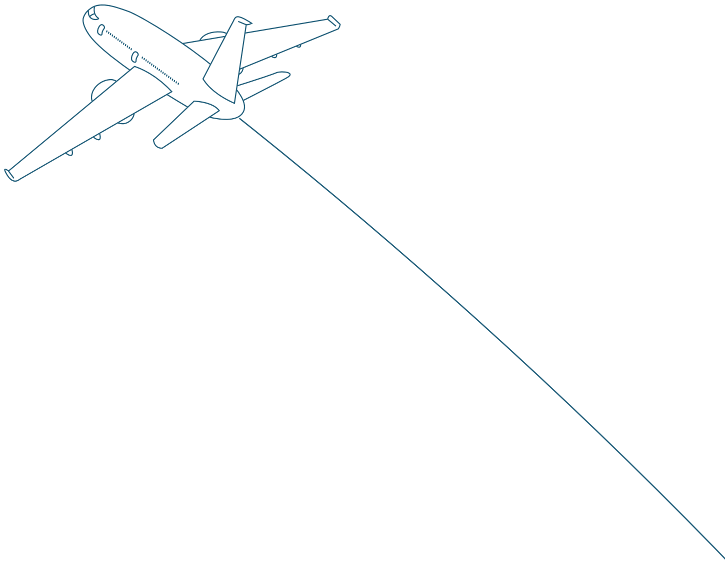
The aviation industry has shown incredible resilience as it continues its intense focus on recovery from the pandemic. What I've been most impressed by in all of this is the collective desire to seize this opportunity – an opportunity to not only rebuild, but to come back even stronger.

We all know just how critical technology is to the day-to-day operations of the aviation industry. It's these innovations that have got us this far – but this is just the beginning. This report paves the way for the future of the sector, by focusing on what matters most: the needs of airline passengers and the individual needs of each part of the aviation ecosystem, from airlines to airports, airspace to aircraft.

Alongside Cranfield, we have mapped out the technologies that will bring this future into existence. Digital Connectivity will enable and accelerate the rapidly changing needs of air travellers and of the aviation sector itself. The report discusses specific challenges and opportunities that, if addressed, will have a direct effect on the sector's resilience, its contribution to reducing climate change, and to new customer service offerings that will enhance the passenger experience and willingness to travel in the post-pandemic world.

This is a defining moment in the future of aviation. Harnessing the technological innovations explored in this report will be nothing short of revolutionary for our industry, and at Inmarsat, we can't wait to play our part in bringing this to life.

FOREWORD



Professor Karen Holford CBE FREng,
Chief Executive and Vice-Chancellor,
Cranfield University

While this is a time of great challenge for the industry, reports such as this one show the path that technology can put us on towards a brighter and more sustainable future.

I have been struck over recent months with the spirit of collaboration among business, past rivalries put aside and a laser-like focus on how we renew and rebuild the aviation industry. At Cranfield, we have been responsible for bringing together manufacturers, airlines, regulators and academia to champion new ways of working and I'm delighted that this report – with our partners Inmarsat – continues to build on that work.

Throughout all our discussions there is clear consensus that the role of technology will be critical in a rebuilt industry. In a highly regulated arena such as aerospace and aviation this will not come without further challenges, but through the partnership commitments of industry and regulators we are already seeing signs of progress.

If we are to create the sustainable industry we all want to see then one thing is clear. 'Digital Aviation' and the foundation of connectivity needs to stop being just be a concept of tomorrow and become the reality of today.

While other industries have embedded digital technology into their business models, often our practices have lagged behind. If we want to see developments such as zero emission flight, the integration of manned and unmanned air and land vehicles and the digitalisation of airspace, then we must seize the spirit of collaboration, strengthen our partnerships and deliver not just for our industry but for the global society that relies on us.

This report sets out the many technological possibilities and what can be achieved in the short to medium term. What is needed now is for us all to redouble our efforts to make them a reality.

CRANFIELD AUTHOR TEAM

Coordinating Author:

Dr. Adrian C. Cole,
CEng, FIMechE, FRAeS
Programme Manager
Digital Aviation Research & Technology Centre

Contributing Authors:

Professor Ian Jennions
CEng, FIMechE, FASME, FRAeS, FPHM, FSAE
Technical Director
Centre for Integrated Vehicle Health Management

Professor Keith Mason
FRAeS, SFHEA
Professor of Air Transport Management
Centre for Air Transport Management

Jim Angus
CEng CPhys MBA MInstP FRAeS
Commercial Director
Centre for Integrated Vehicle Health Management

Dr Thomas Budd
Senior Lecturer
Centre for Air Transport Management

Dr Saba Al-Rubaye
CEng AFHEA MIET SMIEEE UAS-Pilot
Reader in Autonomous and Connected Systems
Centre for Autonomous and Cyberphysical Systems

Dr Dimitrios Panagiotakopoulos
Senior Lecturer in Advanced Air Mobility
Centre for Autonomous and Cyberphysical Systems

EXECUTIVE SUMMARY

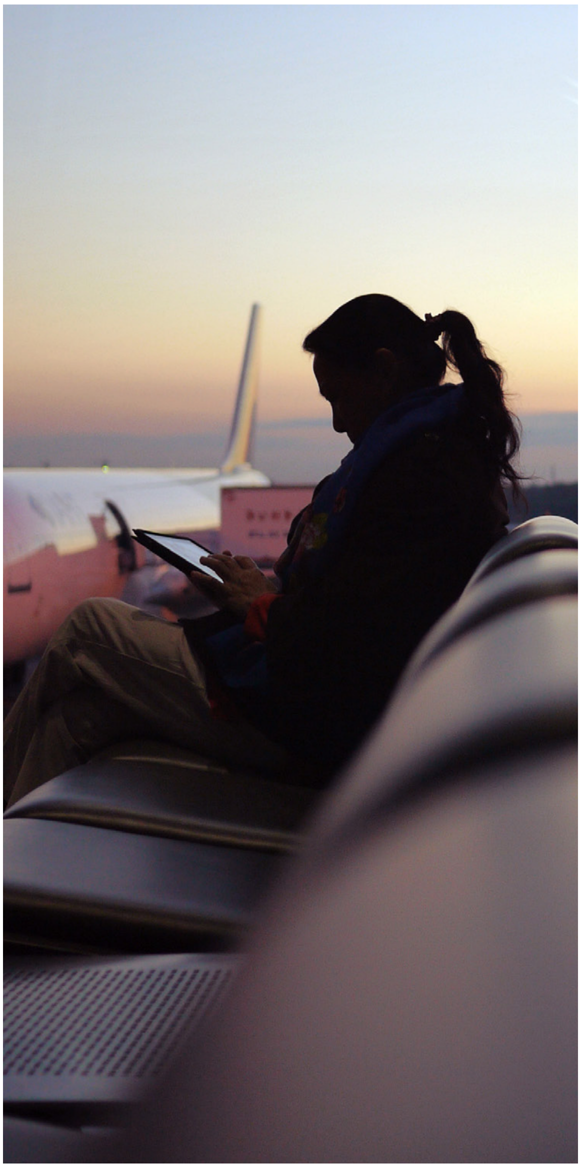
The backdrop to this report has been the most significant shift in global human behaviour for a generation. The pandemic's impact has been felt across all parts of society and not least in the global aviation sector. In addition, the increased awareness of the impact of climate change caused by human behaviour, including transport, has helped create a 'perfect storm' that is causing the sector's key industry stakeholders, its customers and governments across the globe to fundamentally reconsider their priorities and the sector's future service offering. What is clear, as never before, is that while there is consensus for change, the pace and direction still remains uncertain.

This paper has considered how the role of Digital Connectivity, in all its forms, can enable and accelerate the rapidly changing needs of air travellers and of the aviation sector itself. The paper has identified specific challenges and opportunities that, if addressed, will have a direct effect on the sector's resilience, its contribution to reducing climate change and to new customer service offerings that will enhance passengers' willingness to travel in the post pandemic world.

For the vast majority of the aviation sector digital connectivity is about sharing and integrating data into every aspect of their operations in order to enhance operational efficiencies and create new services. New aircraft-based technologies and standards are giving rise to both the 'Connected Aircraft' and 'Connected Cockpit' connected-anywhere concepts that have fully-connected digital ecosystems, with secure, high-bandwidth satellite connectivity alongside a combination of radio and internet streaming using heterogenous technology (5G, LTE, Wi-Fi and commercial networks) where terabytes of data are routinely transmitted. Similarly, initiatives such as next generation flight management systems are being developed that will be based on data-centric cockpit connectivity which are capable of feeding all the global air traffic data streams into an aircraft's flight plan in real- time. Pilots and flight crew will also be using new EFB (Electronic Flight Bag) applications that will provide inflight optimisation opportunities, alerting a pilot if there is the potential to save fuel during a flight. Looking further into the future an entirely new thinking towards aircraft performance management is evolving in the form of the 'Conscious Aircraft' which through self-sensing and monitoring of a system's components can either suggest appropriate maintenance actions or take action itself so creating the potential for a zero-maintenance aircraft platform.

Airports are at the centre of any digital aviation communications infrastructure, managing local aircraft movement, the movement of passengers, their baggage and transiting cargo. Multiple ground-based systems using high frequency data links support airport surface operations, collaborative Air Traffic Management (ATM), weather and navigation information flows. The pandemic and the concern over climate change have, however, changed society's attitude towards air travel, causing both airports and airlines to reconsider their service offerings and business models. Air travel needs to be made; safe, workable and convenient and most of all airlines and airports, with their supply chains and collaborators, will need to be able to adapt rapidly to changing market needs. Increased biosafety awareness has accelerated the introduction of a variety of new digital technologies including; 'health passports', touchless identity screening, virtual queuing and airport flow management that together are enabling safe, seamless movement through airports by reducing contact points, increasing border bio security and so restoring passenger confidence in travel. Digital infrastructures are being required to create more efficient wayfinding for passengers through the airport, more intelligent and responsive baggage tracking and real-time updates on the condition and progress of cargo in transit. Similarly, passengers are demanding that they are better informed when there are unavoidable weather-related disruptions and that alternative personalised travel arrangements are made available to them in a timely manner via their smartphones and tablets. To provide these new capabilities airports of the future are likely to increasingly rely on forms of ultra-reliable, low-latency 5G provision, with very high data rates. Satellite-enabled provision, although having an initial infrastructure cost challenge, when linked with cellular and terrestrial networks, will give service providers additional flexibility. For both the airports and airlines the rapid growth of piecemeal communications technologies has however created a mix of new, legacy and obsolete technologies, so creating complexity, latency, reliability, and scalability concerns. Fully network-enabled, integrated aircraft-airport-airspace systems providing essential real-time command and control support that incorporates both radio-based infrastructures as well as satellite-based communications systems are considered as the preferred direction of travel.

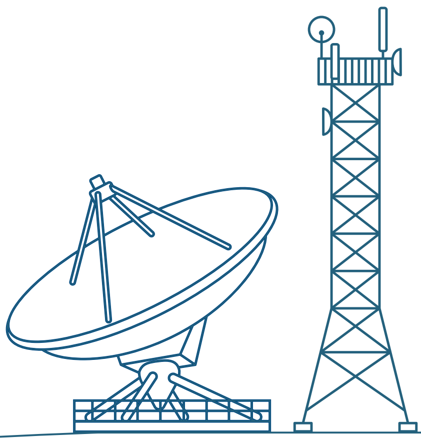
Inflight passengers and crew are now expecting the same levels of personal digital connectivity as they experience in their everyday lives. Digital Inflight Entertainment (IFE) services, for example, that were once only provided by the premium long-haul carriers are now having to be considered by the low-cost carriers. Providing



seamless connectivity to passengers' own tablet and smartphone devices is seen as a means of avoiding costly and heavy aircraft upgrades and potentially introducing new IFE service revenue streams through subscription or third-party advertising for carriers in both the premium and low-cost segments. Beyond IFE, new digital services could support a greater sensing of individual passenger wellbeing (e.g. anxiety levels) and service satisfaction, provide individual onward travel information, support onboard virtual queueing for toilets, and meal distribution. The overall effect would be to provide an enhanced and most importantly personal inflight service.

The future management of highly congested global airspace was being addressed before the current climate and pandemic pressures, and remains of significant concern to a sector that is facing both an airspace 'capacity crunch' as early as 2040, and the rapid rise in new unmanned aerial systems (UASs) that are wishing to operate in the same congested airspace. The only means of managing future airspace will be through the introduction of automation working alongside conventional manned air traffic management systems. The adoption of new network-enabled digital data link services is a growing trend and is seen as a means of reducing the demands on current Air Traffic Controller voice commands. Underpinning the data link services is the need for resilient global and high-capacity satellite-based networks, such as European SESAR Iris programme, that can provide both 4D (three spatial dimensions plus time) and text information and potentially support future 5G integration and handover management. In the near-term data link concepts such as Trajectory Based Operations (TBO) that provide increased aircraft actual and projected inflight positional information (as proposed by Eurocontrol and others) are considered as an important next step. TBO has the potential to increase real-time airspace management efficiency and allows concepts such as 'green descents' to be introduced. In the future, global data links will have the capability of supporting the demand for new autonomous flight systems such as drones and personal air mobility vehicles that are currently creating further technical and regulatory challenges for the global airspace management communities. It is only when true 'Beyond Visual Line of Sight' (BVLOS) autonomous flight is possible within controlled airspace that the predicted market growth opportunities will be realised. This will be achieved through regulatory initiatives such as the SESAR U-space and NASA-FAA UTM programmes, supported by robust and integrated satellite and ground-based surveillance infrastructures with local federated airspace management systems (UTMs) that are able to work alongside traditional voice-based air traffic management systems.

The growth of Artificial Intelligence (AI) and Machine Learning (ML) techniques is impacting on all parts of society including aviation and is seen as critical to driving forward the digital agenda. There are an enormous range of ongoing AI and ML initiatives that if scaled will support new airline service offerings, future airport operations, next generation aircraft and new airspace management. Amongst others AI is expected to be used as a means of text-based autonomous voice recognition and communication between ground Air Traffic Control (ATC) and pilots, so assisting non-native pilots, whereas Machine Learning is expected to be used within operations planning, trajectory prediction and optimisation, situational awareness (weather, terrain) and failure detection/recovery.



CONTENTS

1. DRIVERS OF ACCELERATING CHANGE

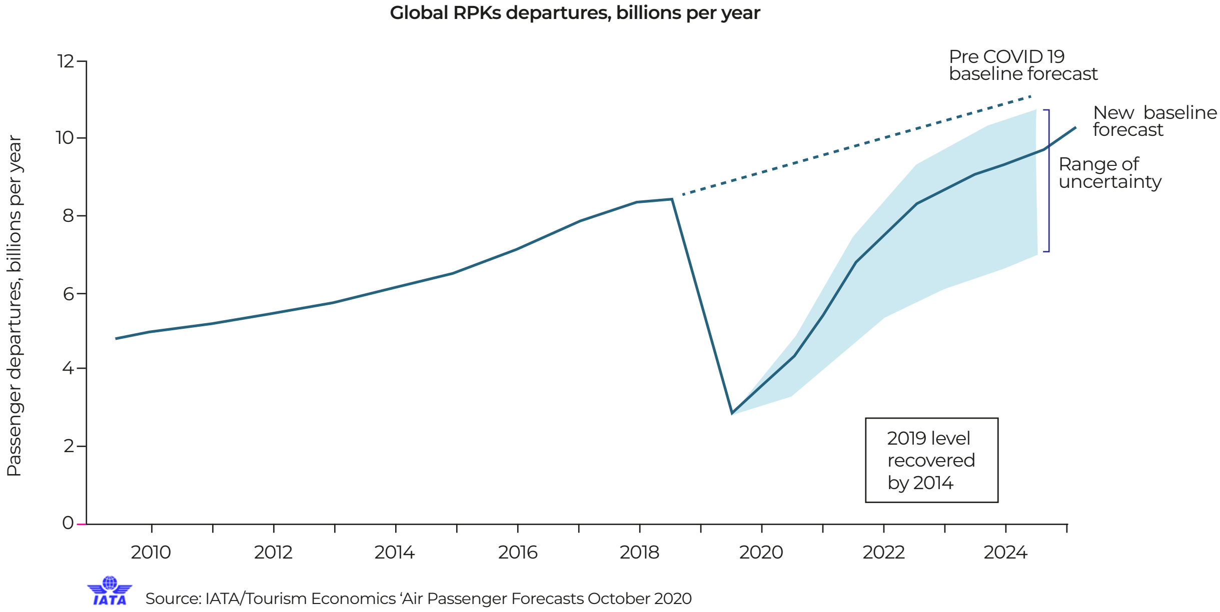
At the beginning of 2019, the aviation sector's greatest challenge was how to both manage growth and live up to its sustainability commitments. Pre-pandemic global passenger numbers were forecasted to double by 2037 to 8.2 billion passenger journeys annually[1] and confidence was strong. Since the COVID-19 pandemic took hold across the world, multiple studies have revealed the realities of the well-publicised collapse in aviation traffic. The EU region lost more than 89% of expected air traffic volumes during 2020, according to one study[2]. Early estimates by ICAO for global travel volumes in 2022 are still dramatically lower than pre pandemic levels at between 27% and 32%[3] and IATA are predicting that they are not expected to return until 2024[4] (Figure 1). Loss of revenues for the sector globally are predicted to be in the region of US$700 billion across the two years 2020 and 2021.

Without downplaying the damaging impacts on sector finances and employment, some commentators[5] argue the pandemic is a one-off opportunity for the entire industry to pause and re-examine risks and benefits. In particular, whether a return to business-as-usual, supported by large state aid payments, is desirable either for the economy or the environment. The volume growth model championed by industry and aviation proponents may have to be replaced, it is argued, with an alternative model of a slimmed-down air transport system that is more resilient for the long-term: both economically less vulnerable and better able to account for its environmental impacts.

Evidence supports the idea that a reduction in air traffic means global environmental benefits. Lockdown events have reduced the

Figure 1

Vaccine news positive but recovery will still take time. Issues with vaccine implementation and the impact of economic damage.



Source: IATA/Tourism Economics 'Air Passenger Forecasts October 2020

[1]https://www.iata.org/en/pressroom/pr/2018-10-24-02/

[2]https://onlinelibrary.wiley.com/doi/full/10.1002/er.5706?casatoken=pvoL36o-9j6oAAAAA%3AFxfPsFkx9E10DVLmyOLGQ2STvZCU8dKh25FAIW7EbX-6AA4p87GmACGGV0Ly8N7AZGzInEPivquebv96f]

[3]https://www.icao.int/sustainability/Documents/COVID-19/ICAO_Coronavirus_Econ_Impact.pdf

[4]IATA/Tourism Economics Air Passenger Forecasts 2020

[5]https://www.sciencedirect.com/science/article/pii/S0969699720305160?casa_to-ken=QKhGGZif9QoAAAAA:EHri_1ROZ5BwGLo6hEkKp7wvW6Ixuqk5g6Yg4PtpnC-jWt5Tp3mxhs04ehm2VbMH5P0NhaYnCs9M

population-weighted concentration of nitrogen dioxide and particulate matter levels by about 60% and 31% respectively (Figure 2)[6]. Consequently, the aviation sector is going to find justifying a return to previous levels of pollution (and higher) increasingly difficult.

At the same time, the pandemic period has raised questions over the necessity of business travel – given the way in which organisations and employees at all levels have embraced remote working, video calls and online interaction – threatening the viability of high margin long-haul business class offerings[7,8]. Airlines are beginning to introduce an alternative 'business class lite' with optional paid-for extras[9] as a means of trying to shore up this market segment.

Figure 2
The pandemic has clearly influenced both global customer expectations and governmental behaviour towards the sector and in so doing has potentially accelerated the ongoing redefinition of global airspace including its management, cyber-security and most of all its future resilience.

29 March 2019

29 March 2020

CUSTOMER EXPECTATIONS

Bio-safety continues to dominate the field of airline customer 'needs'. In an early passenger survey undertaken during August 2020 by IATA data suggested that 79% of passengers were either 'very' or 'somewhat concerned' at the risks from contracting COVID-19 at an airport or on board an aircraft[10]. In September 2021, the Inmarsat passenger confidence survey[11] showed an improving but still alarming picture with 40% of those surveyed were still not confident of flying within six months. Growing awareness of the nature of the aircraft environment – how re-circulating air systems create a relatively safe space[12] – will also play an important part in re-building customer confidence. The COVID-19 pandemic is also playing a role in accelerating trends towards contactless processing and the complete 'contactless journey' through the introduction of multiple systems from catering, to seat and inflight entertainment. These systems use sensors and motion/gesture controls to reduce the number of common touchpoints in the airport and on board the aircraft, where the risk of transmission may be heightened. Equally, trends towards 'bring your own device', where passengers use their smartphone or device to connect with services (for example, inflight entertainment or booking onward travel), have been accelerated by the pandemic. These trends collectively place an increasing reliance on reliable connectivity across the full length of a passenger's door-to-door journey.

Another universal area of need is digital connectivity. Eighteen to 30-year-olds have a strong expectation that Wi-Fi is available throughout travel journeys including flights[13]. Generation Z specifically have further levels of expectation. On average, ultra-connected Generation Z individuals multi-task across a minimum of five devices throughout their day: smartphone, smart TV, laptop, smart watch and tablet[14] and expect a seamless digital experience while travelling. This group are therefore highly

[6]https://www.pnas.org/content/117/32/18984.short
[7]https://www.forbes.com/sites/johnstrickland/2020/08/30/airline-business-travel-are-the-heady-days-over/?sh=5b0be0335570
[8]https://www.researchgate.net/publication/344465082_Covid-19_and_the_long-term_implications_for_the_business_travel_market_Has_Zoom_and_Teams_killed_business_travel
[9]https://onemileatatime.com/finnair-basic-business-class/
[10]"Passenger insights in the times of pandemics, IATA, August 2020]. Understandably the industry has reacted to customer concerns in a variety of ways with additional airport bio-safety measures and through the growing global availability of COVID vaccines with the introduction of digital platforms [https://www.iata.org/en/programs/passenger/travel-pass/
[11]https://www.inmarsat.com/en/insights/aviation/2021/passenger-confidence-tracker-2021.html
[12]https://jamanetwork.com/journals/jama/fullarticle/2771435
[13][https://www.inmarsat.com/en/insights/aviation/2018/making-lasting-connections.html].
[14][https://www.marketingdive.com/ex/mobilemarketer/cms/news/research/18316.html

frustrated by brands that do not allow for the kind of connectivity in the air that they come to expect while on the ground, and will often express their views via social media or indeed vocally during their journey[15]. The omnipresence of digital communications and services in everyday lives means the expectation of digital connectivity is increasingly cross-generational. Indeed the pandemic has accelerated the need for older generations to engage for the first time with digital services such as online purchasing and COVID-19 infection tracking although a study of passenger survey data from Norway[16] has shown that this group (the 'Apprehensive Elders') have the greatest concern about being on board an aircraft and feel less confident to fly than the younger age groups[17]. Digital connectivity will potentially allow for more real-time information and consequently greater ease of travel and delivery of health and wellbeing services in support of all passenger groups.

Modern consumers want to be associated with brands committed to demonstrating accountability and responsibility when it comes to the major global issues of climate change, discrimination and inequality. A pre-COVID-19 study from German consumers in 2019 found two-thirds were influenced by the idea of 'flight shame', conscious of the climate implications of air travel and were in favour of market-based measures to increase the cost of flying, the abolition of subsidies and policies to force airlines to reduce emissions[18]. The pandemic has heightened public sensitivity towards global challenges and the need for fresh thinking and transformational change – making governments and policymakers more likely to take advantage of the groundswell of support for ambitious climate policies. A study[19] during March & April 2021 showed the extent of the public's sensitivity, with over 83% of respondents acknowledging that their personal use of air travel contributes to climate change, a notable increase from the 2019 pre-pandemic study.

GOVERNMENT INTERVENTIONS

During the initial, uncertain and unpredictable, phases of the pandemic, government attention was focused on the short-term survival of the aviation sector, propping up national industries and protecting jobs. The OECD published a report in April 2021[20] on state support to the air transport sector across 26 countries. At the time of publication the combined value of state support (largely in the form of state loans and guarantees) was $38 billion, with the greatest support being provided by the government of United States (€32 billion in 10 year loans via the CARES and CRRSAA Acts) followed by Germany, Spain, France and Japan.

The attention of governments and international aviation governance bodies had been occupied by the twin challenges of flight congestion and reducing atmospheric pollution through better airspace management and alternative low (or zero) carbon propulsion systems. Pre-pandemic the threats of capacity shortfall had been clear: global passenger numbers forecasted to double by 2037[21] and forecasts of a boom in drone flight activity (400,000 Unmanned Aerial Vehicles in EU airspace by 2050[22]). The severe levels of congestion in European airspace had forced the EU countries to implement a punitive framework of fines on the sector (Flight Compensation Regulation 261/2004 [EU261]) in an effort to force airspace efficiency improvements.

[15] [https://blog-digital.travelport.com/preparing-for-the-next-generation-of-travellers-engaging-generation-z]

[16] [https://www.sciencedirect.com/science/article/abs/pii/S096969972030449X?casa_token=uo6ttEXW2p0AAAAA:ToMptDZsX_Z3TQxOOOEQ1PIfkiRcym4uerlgrN80OIuly-E5FFgfjBkUqrMKvxVvnCgzYIQF9MqU]

[17] [https://www.sciencedirect.com/science/article/abs/pii/S095965262032062X?casa_token=z6dE0-NpPgUAAAAA:XNhVa8agENSdyvQ8JWqonF92eglQhfNuFMbvM-dyRBD8g6US7Qpj6192sDTdvGVeUsZhIr2p794k]

[18] https://www.oecd.org/corporate/State-Support-to-the-Air-Transport-Sector-Monitoring-Developments-Related-to-the-COVID-19-Crisis.pdf

[19] https://www.iata.org/en/pressroom/pr/2018-10-24-02/

[20] https://www.sesarju.eu/sites/default/files/documents/reports/European_Drones_Outlook_Study_2016.pdf

[21] http://www.oecd.org/coronavirus/policy-responses/covid-19-and-the-low-carbon-transition-impacts-and-possible-policy-responses-749738fc/

[22] http://www.oecd.org/coronavirus/policy-responses/covid-19-and-the-aviation-industry-impact-and-policy-responses-26d521c1/#section-d1e370

The picture is now more fraught and complex. But it is likely that pre-COVID-19 challenges of congestion and pollution will re-emerge as the practical restrictions and psychological effects of the pandemic diminish. The permanent grounding of a large number of older and less efficient aircraft will have a positive impact on the ability of airlines to meet sustainability targets – while at the same time, without government support, the financial crisis caused by the pandemic could delay investment in new cleaner technologies[23] and airspace management systems. In terms of government attitudes and policy overall, what the pandemic has done is allow for the opportunity to reconsider future transport policies from a holistic perspective and the role of air travel. And in some cases, particularly in the context of short-haul and domestic air routes, this has meant arguments for high-speed rail infrastructure as an alternative to air travel have come to the fore[24].

THE NEW AIRSPACE

The speed and exact nature of the recovery in air traffic remains uncertain in 2021. The scale of previous problems of congestion, combined with the new impetus for the market and revenue opportunities offered by Unmanned Aerial Systems (UAS), suggest that structural airspace management redesign is required in order to avoid the airspace equivalent of gridlock. Since 1999, Eurocontrol's Single European Sky (SES) initiative has led the efforts to improve EU airspace management efficiency[25] within a difficult context of traffic growth, more diversity in modes of air travel and the need to co-ordinate the work of different regulatory authorities.

Unfortunately, current airspace traffic management (ATM) is relatively manual and unsuited to the high levels of complexity that are expected on the airspace horizon: dependent on training skilled air traffic controllers to provide rigorous oversight of airspace sectors, mostly through voice communications. In order to effectively address the anticipated traffic growth and need for more green and efficient traffic flows, as well as to prepare for the introduction of new entrants such as UAS, the current ATM system and new UTM system will need to harmonised. Together they will need to be able to cope with multiple dimensions of airspace systems and unique challenges, including very low level airspace operations and particular issues posed by manned/unmanned coexistence around airports. Effective and efficient human/autonomous system communications will be essential in managing this complexity.

Progress towards a shared manned and unmanned airspace is becoming rapid. As one example, the €3.7 billion SES ATM Research Joint Undertaking programme (SESAR-JU) is preparing the environment for remotely piloted drones in low altitude, civilian, uncontrolled airspace. Involving 25 European Airports and 11 universities, the SESAR programme has created an overarching 'concept of operations' for the safe operation of low altitude drone operations within a so-called 'U-space' architecture, the basis of a pan-European Unmanned Aircraft Traffic Management System (UTM)[26]. The SESAR initiative is not the only

[23] http://www.oecd.org/coronavirus/policy-responses/covid-19-and-the-low-carbon-transition-impacts-and-possible-policy-responses-749738fc/

[24] http://www.oecd.org/coronavirus/policy-responses/covid-19-and-the-aviation-industry-impact-and-policy-responses-26d521c1/#section-d1e370

[25] https://link.springer.com/article/10.1007/s10846-020-01185-1

[26] https://www.sesarju.eu/sites/default/files/documents/reports/U-space%20research%20innovation%20results.pdf

programme addressing this challenge. In the US, the Federal Aviation Authority's NextGen programme[27] has published its own concept of operations[28] and similarly the UK's emerging Open UTM Service[29] and Future Flight programmes[30] are jointly addressing the challenges of multiple UTM service provider integration and autonomous BVLOS flight. There's also Eurocontrol's ATM Master Plan, EASA's EPAS, and NASA's Advanced Air Mobility programmes.

ESSENTIAL CYBERSECURITY

Increased demands for connectivity in aviation, both on infrastructure (e.g. through the introduction of U-space) and direct customer services, create a corresponding increase in the opportunity for cyber-attack from criminal groups, terrorists and hostile governments.

The breadth and depth of technologies being used – like machine learning and 5G telecommunications – means the digital 'attack surface' that the aviation sector presents to its adversaries will continue to grow. Digital aviation is evolving in such a way that keeping up with latest developments and networked operations in order to manage risk remains difficult[31]. An additional channel of concern is the dependence on satellite communications. A major part of the world's critical infrastructure, including aerospace, now depends on the expanding global satellite networks which are as vulnerable to cyber-attack as their equivalent ground infrastructures[32].

Cybersecurity is a priority of the global aviation community. Critically, the Aviation Cybersecurity Strategy (Resolution A40-10)[33] set up by the ICAO has established a cohesive approach to the challenge. This is backed up by a shared, cross-industry recognition that only when there is full implementation of all countermeasures throughout the sector ("no vulnerability is left behind") will the appropriate level of safety assurance be achieved.

SECTOR RESILIENCE

Aviation is just one part of a complex, interconnected and interdependent global system of systems. Airports, airlines and engineering supply chains might be able to reduce levels of risk to their operations – making them ever safer, more secure and sustainable – but as the pandemic has illustrated so grimly, the outside world they rely on will always be imperfect.

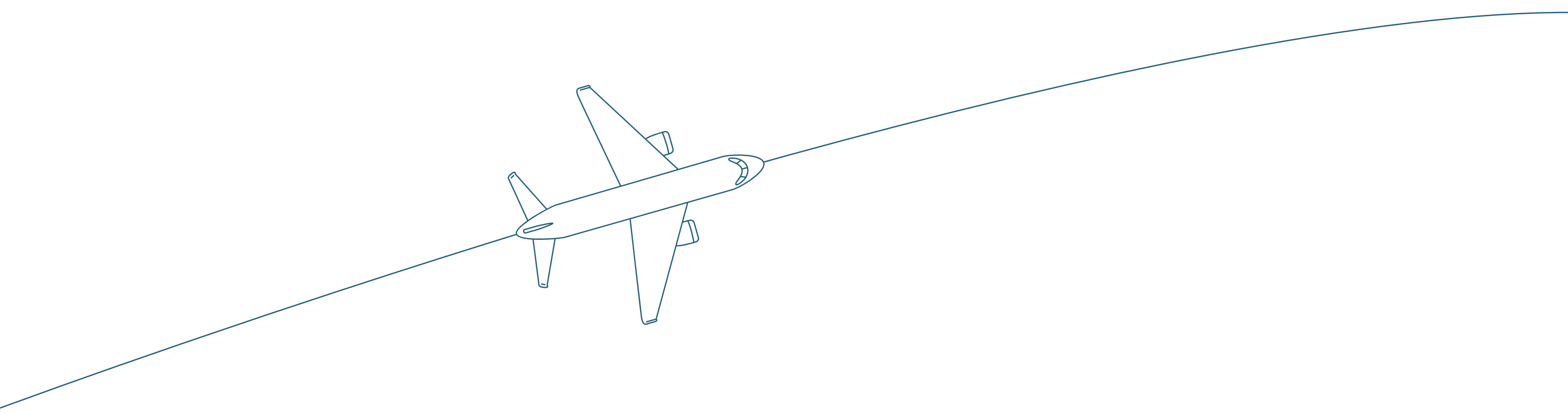
Resilience in a changing global climate is becoming the dominant challenge. More severe weather, increased localised rainfall and surface temperatures, changing average winds, shifting bird populations, are all having an impact on aviation. All the evidence from the natural world, such as the increasing number and frequency of extreme weather events, is that we are at the beginning of a series of even bigger waves of change, creating more extreme events and

[27]https://www.faa.gov/nextgen/
[28]https://www.faa.gov/uas/research_development/traffic_management/media/UTM_ConOps_v2.pdf
[29]https://cp.catapult.org.uk/wp-content/uploads/2020/12/01296_Open-Access-UTM-Report-V4.pdf
[30]https://ktn-uk.org/transport/future-flight/
[31]"https://www.atlanticcouncil.org/in-depth-research-reports/report/aviation-cybersecurity-scoping-the-challenge-report/
[32]https://arc.aiaa.org/doi/abs/10.2514/6.2020-4116
[33]Aviation Cybersecurity Strategy," International Civil Aviation Organization, October 2019,

challenges, and that climate change is the towering wave above everything else[34]. Major reductions in carbon emissions are therefore an essential part of establishing resilience in aviation. Targets set by the UK government and the European Union, alongside ambitions outlined in the Paris Agreement, all mean growing scrutiny – an attention that will only intensify post-COVID-19, stiffened by expectations of change and reductions in demand being used as an opportunity for transformation. Working with climate models from the MET Office and UK defence and security partners, predictions are being made at a global scale on the future of aviation[35], leading to a basis for better informed decision-making on the real returns on investment into sustainable aviation technologies as well as air transport in different areas of the world.

Resilience in system design and reliability will always be fundamental. The sophistication and order fulfilment requirements of new aircraft technologies means more pressure on cycles of testing and the need for alert systems of monitoring and maintenance. Recent events have shown how even sector leaders have found these pressures can have significant financial and human costs if they are not managed. Rolls-Royce faced three major performance issues simultaneously with the turbine blades on the Trent 1000 engine supplied to Boeing's 787 Dreamliner fleet. Although the issues are now believed to be resolved[36], Rolls-Royce is expected to incur additional costs of £2.3 billion by 2023 as a result[37]. Boeing themselves have also suffered directly through failures in avionics system design in their 737 MAX fleet, relating to the loss of 346 lives in two separate aircraft crashes. While the Federal Aviation Authority in the US has now given approval for the 737 MAX to resume flying again, the impact on future global sales and customer trust will be felt for many years to come.

Sector economic resilience has been tested to the extreme. The economic shock of the pandemic for airlines has demonstrated the extent to which there is a wider, interdependent ecosystem of businesses. With just an estimated 60% of global passenger flight capacity being used during 2021, significant numbers of the global fleet are not expected to ever to return into service[38], causing a disruption to the aftermarket parts industry due to oversupply of used components. The permanent grounding of older and less efficient aircraft is being welcomed on environmental grounds, but the consequences of a smaller global fleet will be significant. Potential sector re-sizing provides an opportunity to re-examine the risks and benefits of the current volume growth business model (relying on large-scale state funding to continue), and to question whether alternatives might deliver a more resilient and sustainable future within the context of the 'new normal'[39].



[34]https://www.ipcc.ch/report/ar6/wg1/

[35]https://www.turing.ac.uk/research/research-projects/climate-security

[36]https://www.flightglobal.com/air-transport/rolls-royce-clears-parked-787-backlog-after-trent-1000-blade-progress/139221.article

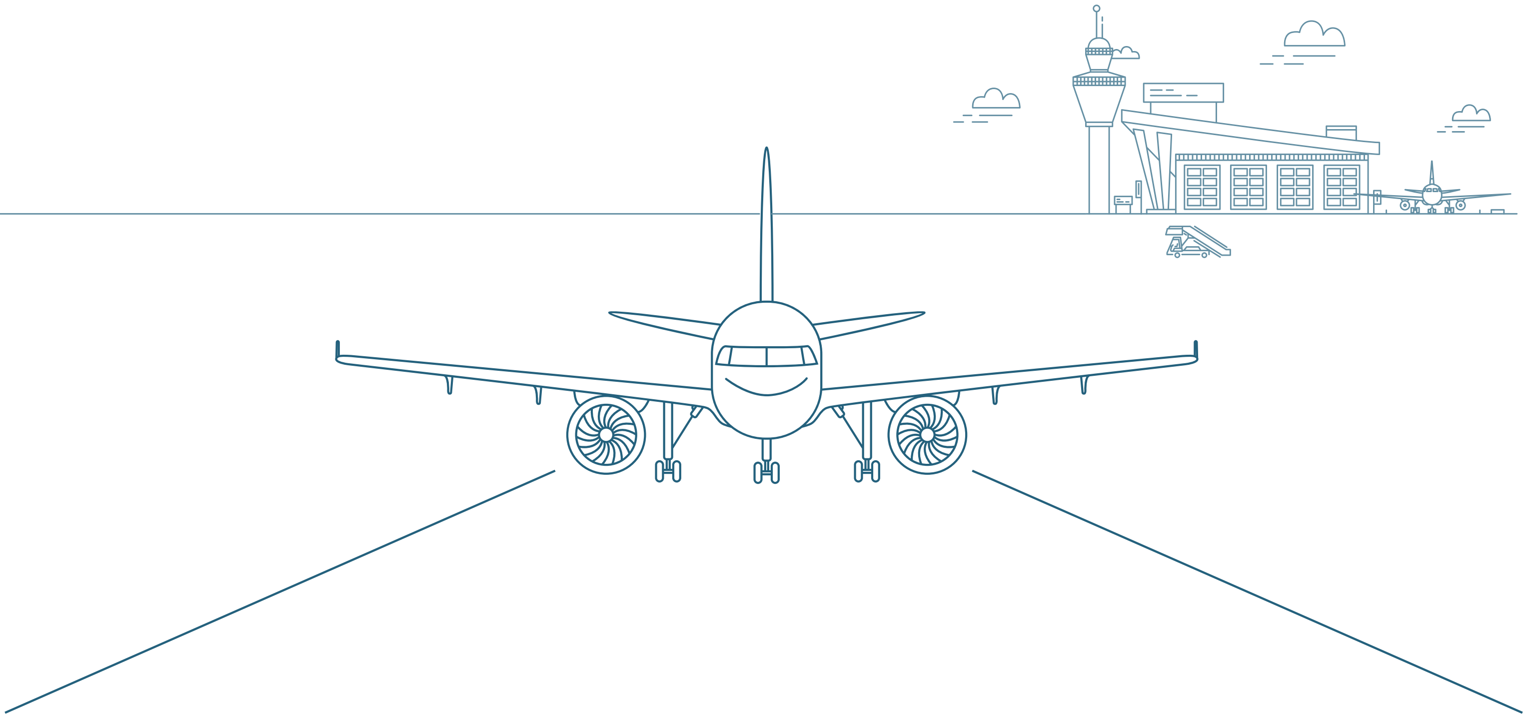
[37]https://www.ft.com/content/8d96dc32-dc70-408b-8739-9b84671b5670

[38]https://www.reuters.com/article/us-health-coronavirus-aviation-focus-idUSKBN26405X

[39]"https://www.sciencedirect.com/science/article/pii/S0969699720305160?casa_token=QKhGG-Zif9QoAAAAA:EHri_1ROZ5BwGLo6hEkKp7wvW6Ixuqk5g6Yg4PtpnCjWt5Tp3mxhs04ehm-2VbMH5P0NhaYnCs9M

CONCLUSION

The pandemic has shifted the behaviour of key stakeholders in the aviation sector; customers, governments and the airlines themselves are reconsidering their priorities and the sector's future service offering. In some instances, the pandemic has helped accelerate efforts towards a more efficient and secure airspace that is fit for the future, but most of all it has created a new stronger focus on the sector's use of digital data. Whether considering climate change, system design and reliability or economic resilience, the acquisition of new and higher quality data from across the entire sector will be increasingly important for building a sustainable future for the aviation system as a whole. Data will be needed for anticipating risks and ensuring there is greater cross-sector flexibility to deal with them; for testing the alternative technologies needed for a sustainable aviation business; to develop new kinds of shared frameworks, systems and technologies; and for improving and ensuring cybersecurity.



2. THE AVIATION ECOSYSTEM AND TIME HORIZONS

Conventional definitions of 'aviation' and 'aerospace' understandably are centred on the aircraft[40,41,42], however they tell us nothing about the structure and complexity of the aviation industry and only hint at its considerable breadth. Most importantly, these definitions highlight an attitude that appears to limit the essential vision for development. For example, current industry drivers – beyond the immediate responses to threats from the COVID-19 pandemic – appear to continue to focus primarily on the aircraft, and in particular on the reduction and eventual elimination of aircraft carbon emissions, the so called 'Green Recovery'.

Multiple industry reports concentrate on aircraft-centric technology roadmaps towards the net zero global emissions reduction target by 2050[43]. The IATA Fly Net Zero commitment sets out an ambitious timeline for developing aircraft technologies, geared specifically towards meeting the industry's goals for sustainability. Not unexpectantly the role of alternative sustainable aviation fuels (such as biofuels and hydrogen) and electrification feature strongly, providing 65% and 13% of the emissions reduction benefit respectively. The same commitment acknowledges the potential minor emissions benefits gained through improvements in airspace management efficiency (circa 3%). The impact of any improvements in aircraft design, be they evolutionary or revolutionary, will be dependent on whether they are fully integrated into the wider system of operations. During a period when finding efficiencies – both financially and for carbon emissions reduction – is imperative, the full benefits of each and every next generation design innovation needs to be realised.

While these kinds of roadmap reports are useful in helping to create a consistency of long-term direction across parts of the industry (aircraft design and manufacture especially), they fail to recognise the alternative drivers and timescales that are influencing the other important elements of the industry. Without a truly holistic approach to future road-mapping that is shared across airlines, airports and airspace as well as aircraft, significant change is unlikely to happen. A broad vision for the sector is needed, one that includes all its major elements but also, and most crucially, with the airline passenger at its heart. We might call this holistic view a '5As' view.

Figure 3: The 5As – A Holistic Aviation View

[40]Oxford Languages: "the flying or operating of aircraft"

[41]Cambridge Dictionary: "the activity of flying aircraft or of designing, producing and keeping them in good condition"

[42]www.askdifference.com/aerospace-vs-aviation: "engineering effort to fly in the atmosphere of Earth (aeronautics) and surrounding space (astronautics)"

[43]https://www.iata.org/en/iata-repository/pressroom/presentations/environment-net-zero-carbon-at-iata-agm-2021/

Viewing the sector through the 5As lens gives the opportunity for a more equal balance towards the development of future advances across the sector's major elements while acknowledging their inter-relationship. The 5As approach also ensures that an understanding is rooted in the industry's relationship with its primary customers, the airline passenger or commercial freight customer, and that, ultimately, they are the drivers of change, whether through individual expressions of desire or through their national governmental voices.

The above approach also encourages acknowledgment of how quickly each sector element is capable of responding to its own drivers for change and how such individual timescales impact the airline passenger.

> "From an engineer's point of view, it seems pretty thankless to spend years, say, optimising an aeroplane to deliver the best efficiency and fuel-burn performance, and then have passengers in that plane doing three or four loops of an airport waiting to land, or spending hours on the ground at an airport. The greatest immediate efficiencies will come from linking together airspace, airports and airlines. And that means the sector needs to be building a connected digital infrastructure, introducing new technologies and standards now."

Professor Iain Gray,
Director of Aerospace, Cranfield University;
formerly Managing Director, Airbus UK.

	Change Cycle Time Scale		
	Minor Minor changes and upgrades	Medium Significant changes within existing structures and concepts	Major New structures and concepts
Airline Operations	3 to 6 months	6 to 12 months	1 to 2 years
Aircraft Design & Manufacture	2 years	3 to 4 years	8 to 10 years
Airspace Management	6 to 12 months	1 to 3 years	10 to 20 years
Airport Operations	1 to 3 years	5 to 10 years	20 to 50 years

The above table highlights the considerable range of change cycle times that are the norm across the industry elements extending from just a few months to decades for major changes to international airspace management and to airport infrastructure. Given the strong interdependences between the sector elements, the significantly different cycle times will undoubtedly cause cross-sector tension, with the industry's customer base ultimately being the loser.

The structure of this paper broadly follows the above 5As and specifically explores the digital technologies and process changes that are anticipated within each sector element, with a particular focus on those likely to occur within the next 10 years.

The underpinning theme throughout the paper is a consideration of the benefits of the technologies to the sector's ultimate customer the **Airline Passenger** and it therefore forms the paper's backbone that runs through the remaining four sector themes.

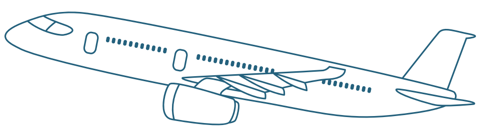
The paper starts with the **Aircraft** and considers the connectivity opportunities and challenges associated with its ability to exchange and use ever-increasing amounts of data. This section also introduces a forward-thinking Conscious Aircraft as a concept that might define how an aircraft of the future might have a heightened awareness of itself.

The paper then considers the **Airlines** and the role of connectivity in providing new and enhanced services to an industry that has been on the receiving end of the COVID-19 pandemic and is having in some cases to redefine its business models, whether it operates in the short-haul or long-haul markets.

The role of the satellite communications industry in the shaping of future **Airspace** connectivity is discussed with particular emphasis on key drivers such as entertainment/broadcasting services and future UAS communications services. Future communications capabilities such as automatic dependent surveillance (ADS), ADS Broadcast (ADS-B), flight plan consistency (FLIPCY) service, system-wide information management (SWIM) system and 5G technology are presented as a means to increasing data link bandwidth.

Airports are considered by some as being at the centre of an aviation communications infrastructure handling vast quantities of data that support the management of local aircraft movement, the direct needs of passengers plus their baggage, transiting cargo or freight plus a multitude of third-party ground and terminal operations. The core digital needs of the airport are therefore reliable, simple to access common data communications platforms that are able to handle all forms of data securely and swiftly.

The paper concludes a short section on the role of **Artificial Intelligence** in aviation. This topic has applications across all the above sector themes and could easily justify an entirely separate paper. The section provided here is a simple introduction to some of the many applications AI is finding within aviation and provides examples of what is and will be being developed in the very near future.



3. THE AIRCRAFT – CONNECTIVITY AND CONSCIOUSNESS

The performance of future aircraft designs will not only be measured in terms of their physical design but how they communicate, share data and integrate with every aspect of their operations.

New communications technologies within the industry will be at the forefront of growth and represent some of the greatest opportunities for the mid- and long-term future. Collectively known as the 'Connected Aircraft' these technologies generally refer to a fully-connected digital ecosystem, with secure, high-bandwidth satellite connectivity where terabytes of data are transmitted to and from the aircraft.

The concept of the Connected Aircraft is now recognised across the industry[44,45] and will undoubtably create new opportunities for improved efficiencies, safety, sustainability and revenue streams across multiple operational domains. There are clear benefits from enhanced data management through onboard connectivity:

- Enabling crews to become better informed to make decisions that reduce fuel consumption
- Optimised flight routing
- Risk avoidance, such responding to real-time weather updates to steer clear of significant weather events
- Relaying timely information on component wear and failure, making it possible for replacement parts to be available and positioned appropriately, avoiding delays.

The challenge comes in finding the balance between disclosure and control. For example, to what extent should sensitive flight or pilot performance information be shared with a third party? Airlines, in particular, need to be smart in how they manage and share data with aviation digital services providers to maximise the potential of their aircraft data while at the same time maintaining control.

The Connected Aircraft will also trigger changes for the sector skills roadmap required for successful aviation and aerospace. There will continue to be importance placed on key science, technology, engineering and manufacturing (STEM) roles, but as a result of these new technologies there will be an evolution in the nature and types of these jobs as the technological advances continue.

Within this chapter the Connected Aircraft concept is examined from both the perspective of the enabling communications technologies and their direct benefit plus how such technologies can help to redefine aircraft management through the adoption of next generation aircraft maintenance practices.

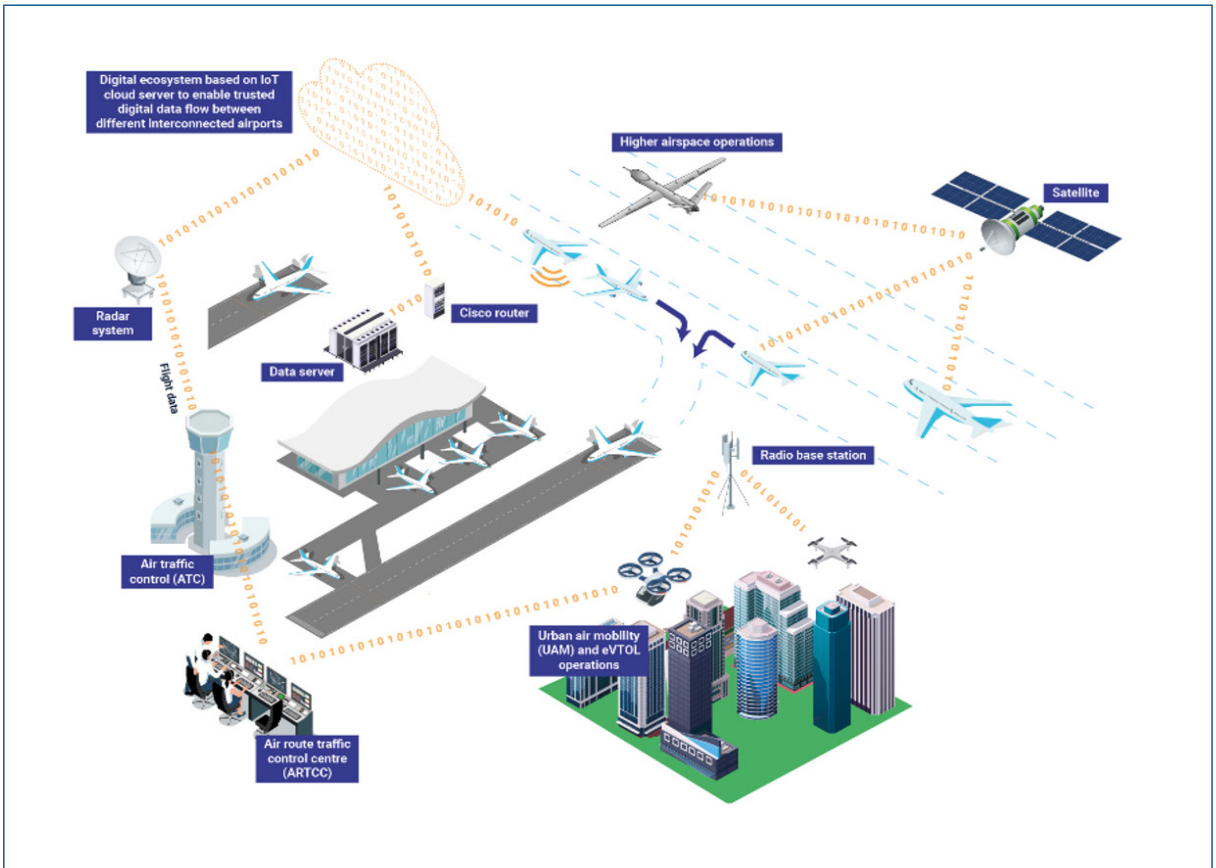
[44]https://www.airbus.com/newsroom/stories/new-era-of-connected-aircraft.html
[45]https://aerospace.honeywell.com/en/learn/connected-aircraft

ENHANCING COCKPIT COMMUNICATIONS, THE CONNECTED COCKPIT AND CONNECTED AIRCRAFT

In the context of crowded skies and predicted sharp rises in the volume of air traffic globally, the development of data-centric cockpit communications is essential for future aircraft operational efficiency and safety. Overall aircraft control systems are the most operationally critical and the most strictly regulated domain when it comes to redundancy management and requirements for aircraft connection stability in all-weather situations. Airlines are today demanding reliable data link capabilities for efficient operations and passenger connectivity, and yet this demand is generating additional system complexity which in itself is creating future equipment lifecycle and legacy challenges.

Today, the main means of data communications for aircraft and pilots, the Aircraft Communications Addressing and Reporting System (ACARS), is bedevilled by congestion and lack of data capacity. Developed in 1978 and operating over VHF communications frequencies (with some Satcom support), ACARS has provided the platform for Air Traffic Control (ATC), Aeronautical Operational Control (AOC) and Airline Administrative Control (AAC) messaging. It is widely accepted that ACARS is becoming overloaded, particularly as the demand for digital data link communications services increases and will not be at the forefront of future sector interest. ACARS will, however, continue to be the foundation for urgent communications. Some attempts to move non-safety communications from VHF using

Figure 4: A vision of aircraft connected system networking



internet broadband channels were trialled in 2015[46] with Cobham's Satcom Aviator 300 Level D Intermediate Gain Antenna (IGA) and Inmarsat's SB-S network. While there are concerns regarding the future of ACARS the more immediate motivation is in addressing the ongoing implementation concerns around ATC to Pilot Data Link Communications (CPDLC) for sharing safety services messages. In Europe, CPDLC has been required above FL285[47] from February 2020 although there are still significant gaps in coverage. CPDLC also is dependent on the capacity of VHF communications frequencies.

Next generation flight management systems will be based on data centric cockpit connectivity systems that are separate from the cabin systems and are capable of feeding all the global air traffic data streams into an aircraft's flight plan in real-time. The so called 'Connected Cockpit' and 'Connected Aircraft' concepts. These concepts consider a single system that is based on Internet Protocol technology, capable of transmitting data through multiple data links, directly to the ground and via satellite, digitally and at high speed, providing communication services for all aircraft needs, each with its own required quality of service and in a seamless way. The Connected Cockpit is, for example, already providing the opportunity for satellite-derived, real-time turbulence forecasting and navigating around clear air turbulence[49] and greater pilot-to-ground data communication allowing pilots to send a variety of data – including imagery – to the ground team for collaborative problem solving, instead of having to rely on voice-only communication. Recently introduced systems such as PureFlyt[50] offer an integrated flight management system that supports flight preparation, delivers flight information to the cockpit crew, sets flight optimisation procedures and ensures aircraft guidance as the flight plan progresses, using both onboard and real-world data, such as weather information.

COMMUNICATIONS AND AIRCRAFT MAINTENANCE – THE CONSCIOUS AIRCRAFT

The ability of aircraft to generate data has leapt forward. Data on thousands of health parameters; engine performance, pressure, rotor speeds, temperatures, vibration, can all be communicated to the ground in real-time for health monitoring. Compared with traditional aircraft, the new generation models are expected to produce 30 times more data[51]. A Boeing 787 can generate 500GB of data per flight[52]. By 2026, the total amount of data generated by aircraft is estimated to grow to 98 billion gigabytes each year[53]. In calculations made by Rolls-Royce in 2019, operational data volumes are doubling each year, meaning the company expects the global fleet including Rolls-Royce engines to generate 98 exabytes of data (an exabyte is one billion gigabytes)[54].

As a result of the rapidly increasing availability of aircraft technical performance data, the field of Integrated Vehicle Health Management (IVHM) is becoming an established approach to prognostics: the transformation of system data from sensors into information that can be used to support operational decisions. The main aim of health management is to remove the costs and issues posed by unscheduled maintenance. The core aircraft components – the components that are already regularly monitored and assessed – are less the issue. Disruptive events come from surprises, where deterioration or damage in minor components lead to wider faults. With enhanced operational awareness, IVHM aims to minimise time needed for inspections by maintenance; and with early insight on the potential for problems, make it possible to schedule maintenance at more convenient times, ensuring availability of the aircraft is unaffected. Under this model, the cycle of annual or biennial scheduled maintenance is replaced by condition-based maintenance. Reports from sensors are translated by health management algorithms that assess level of

[46] https://www.connectedaviation.com/acars.html

[47] https://www.eurocontrol.int/service/controller-pilot-datalink-communications-our-maastricht-uac

[48] https://ops.group/blog/cpdlc-in-europe/

[49] https://www.aviationtoday.com/2019/01/10/qantas-developing-new-connected-cockpit-applications/

[50] https://onboard.thalesgroup.com/now-on-air-introducing-pureflyt-the-new-generation-flight-management-system/

[51] www.oliverwyman.com/our-expertise/insights/2017/jun/aviation-s- data-science-revolution.html

[52] www.mro-network.com/big-data/using-big-data-schedule-unplanned- maintenance

[53] www.oliverwyman.com/our-expertise/insights/2017/jun/aviation-s- data-science-revolution.html

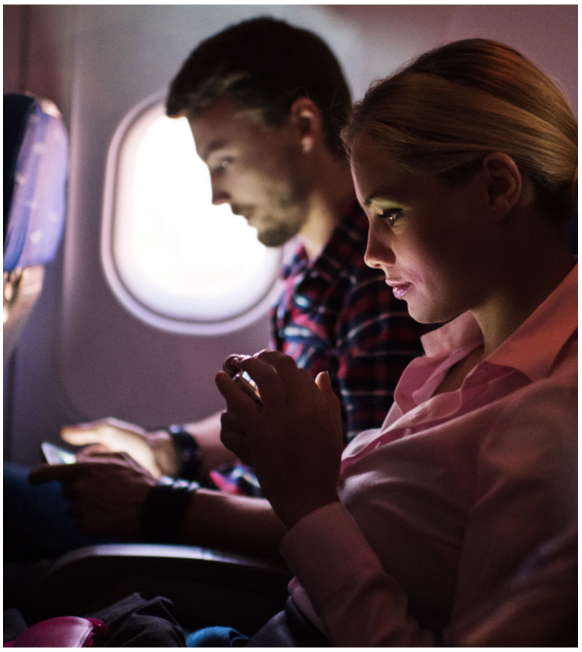
[54] Steve King, Rolls-Royce Engineering Associate Fellow, presentation: 'Big Data Analytics - Alchemy or Data Science?', 12 March 2019.

maintenance need and priority – a form of just-in-time maintenance that reduces engineer time and costs.

Airbus and Boeing are examples of manufacturers developing a predictive maintenance capability via remote diagnostics, including the use of a cloud-based platform to integrate reports and knowledge on operations and maintenance needs. Since 2018, the new Airbus A320s have used a secure server to collect data on 24,000 health parameters and automatically transmit the maintenance data to ground operations (via 4G on the ground and Satcom broadband while in flight rather than ACARS)[55]. But it is not just the aircraft manufacturers who are developing and applying predictive maintenance concepts, Cathay Pacific and Singapore Airlines Group, for example, are known to be working with Honeywell[56] and there are other such partnerships that do not include the OEMs.

Cranfield University[57] has, with its industry partners, had a long-term aspiration to deliver a so-called 'Conscious Aircraft' with the potential for a zero-maintenance aircraft platform. A 'Conscious Aircraft' is defined as one that 'looks after itself', that is aware of its own condition through self-sensing and monitoring component health, and knows its own need for maintenance.

In practice, can an aircraft be 'conscious'? The strict answer is no – because consciousness is more than awareness: it is the awareness of awareness. As theoretical physicist and futurist Michio Kaku[58] has suggested: "Human consciousness is a specific form of consciousness that creates a model of the world and then simulates it in time, by evaluating the past to simulate the future. This requires mediating and evaluating many feedback loops in order to make a decision to achieve a goal." While an aircraft health management system can be aware of the systems and environment around it, it is not sentient or conscious. An aircraft, however, can be 'conscious' in ways that are important to improving aircraft health, maintenance and performance. The Conscious Aircraft initiative aims to achieve the creation of an integrated vehicle health management system that is capable of a fully aware state, able to either suggest appropriate action or take action for itself.



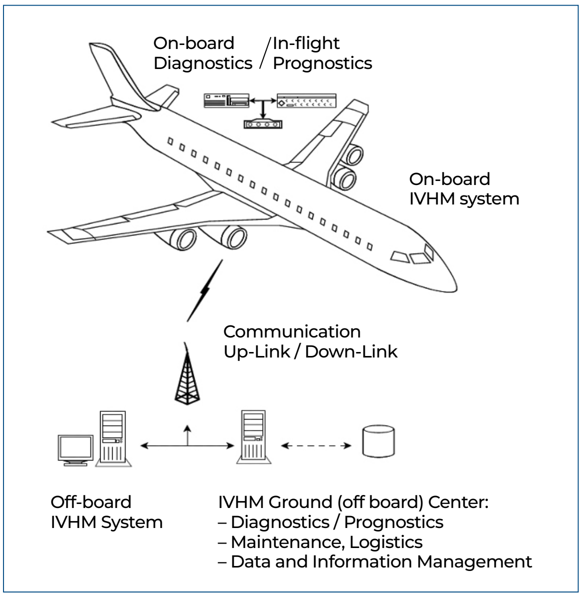
The Conscious Aircraft of the future monitors current platform health, reliably predicting the remaining useful life of components and systems and then automatically reconfiguring them to optimise their remaining life. This means technology that senses every aspect of an aircraft's engineering, connected with a human-like nervous system. An aircraft that is aware of the health of its core organs, its components, and also has a skin – able to sense changes in the external environment, the weather or smoke from an ash cloud. Such a capability will have a major impact on operational efficiency, facilitating more sustainable fleet operations and supporting the introduction of new technologies aimed at reducing emissions and environmental impact. While seamlessly communicating with human operators and engineers, the use of automation and artificial intelligence reduces the reliance on human interactions. Data is synchronised with ground-based systems to optimise how the aircraft is managed throughout its lifecycle, for

[55] www.airbus.com/content/dam/products-and-solutions/services/ Services-by-Airbus-press-conference-for-LBG-June-2017.pdf
[56] https://www.computerweekly.com/blog/Eyes-on-APAC/How-APAC-airlines-are-harnessing-the-IoT
[57] https://www.cranfield.ac.uk/centres/integrated-vehicle-health-management
[58] Michio Kaku, The Future of the Mind, Penguin, 2014.

planning future maintenance, repair and overhaul (MRO) to minimise costs; reducing the risks of unavailability and disruption to services; making it more straightforward for airlines to work with smaller fleets. Ultimately this would lead to a 'zero-maintenance' platform with no surprises for the operator. 'Lights out' MRO hangars – automated facilities which only switch on when they are needed – would be the hub for remote maintenance engineers.

For larger passenger aircraft, it is likely they will have a pilot/operator on board for some time to come. It is therefore essential that the interface between the human brain and the conscious aircraft is 'seamless' and facilitates effective and timely decision-making. This is also required for ground-based maintenance engineers who will continue to be responsible for the airworthiness of the aircraft. This 'seamless' communication will be facilitated by Advanced Human-Machine Interfaces (HMI). A key benefit of self-aware aircraft will be their ability to share that awareness with pilots, operators and engineers. Advanced HMIs – such as brain–computer interfaces[59], synthetic telepathy, brain enhancement and Virtual Reality/Augmented Reality technology – will allow pilots and (digital) engineers to communicate intuitively with aircraft. In turn this will allow for faster and better decisions when unexpected events occur during flights and reduce the risk of accidents caused by human error. A longer-term aspiration, arising from a growing understanding of the way the brain works and how it makes decisions[60], drawing from developments in cognitive and behavioural science[61], is to use advanced HMIs to allow pilots and engineers to sense the health of the aircraft as if it was a part of their own body.

Figure 5



These technologies would open up the opportunity for remote engineering support: where engineers could address problems while aircraft are still in flight or stranded in remote locations, using telepresence systems, given that the communication channels with the aircraft could support these. Similarly, there will be the option of remote piloting: a remote operator with access to aircraft cockpit information and able to take control, providing emergency backup in the event that a pilot is incapacitated, or as a back-up pilot for an autonomous aircraft. Also, HMI can be used to monitor the health of passengers and those with medical conditions, avoiding the need for preventable emergency diversions (for example, in the post-pandemic environment, faster and more effective identification of virus-infected passengers on board the aircraft) via a telepresence.

The operational cost savings of the concept are clear. Each day an aircraft is not in use costs an estimated £200,000[62]. Maintenance overall is estimated to make up 10% of airline costs[63]. In 2018, airlines spent US$75.7 billion on MRO (a figure then expected to reach US$90 billion by 2024)[64,65]. Unscheduled maintenance, where there are 'surprises', is a major issue.
The estimated global costs for unscheduled maintenance due to both delays and cancellations in 2017 was more than US$6.5 billion for wide body jets, almost US$5 billion for small regional jets[66].

[59]https://www.nature.com/articles/s41586-021-03506-2

[60]Roger Penrose, The Emperor's New Mind (1989, 1999, 2016), Oxford University Press, Ch 9

[61]Robert M Sapolsky, Behave: The Biology of Humans at Our Best and Worst, May 2017. Bodley Head

[62]Based on reasonable average estimates: a narrow body aircraft (200 passengers x 8 journeys x £100 = £160,000); wide body (350 passengers x 1 journeys x £800 = £280,000).

[63]www.ft.com/content/3f956a92-0943-11e5-b643-00144feabdc0

[64]https://www.grandviewresearch.com/industry-analysis/aircraft-mro-market

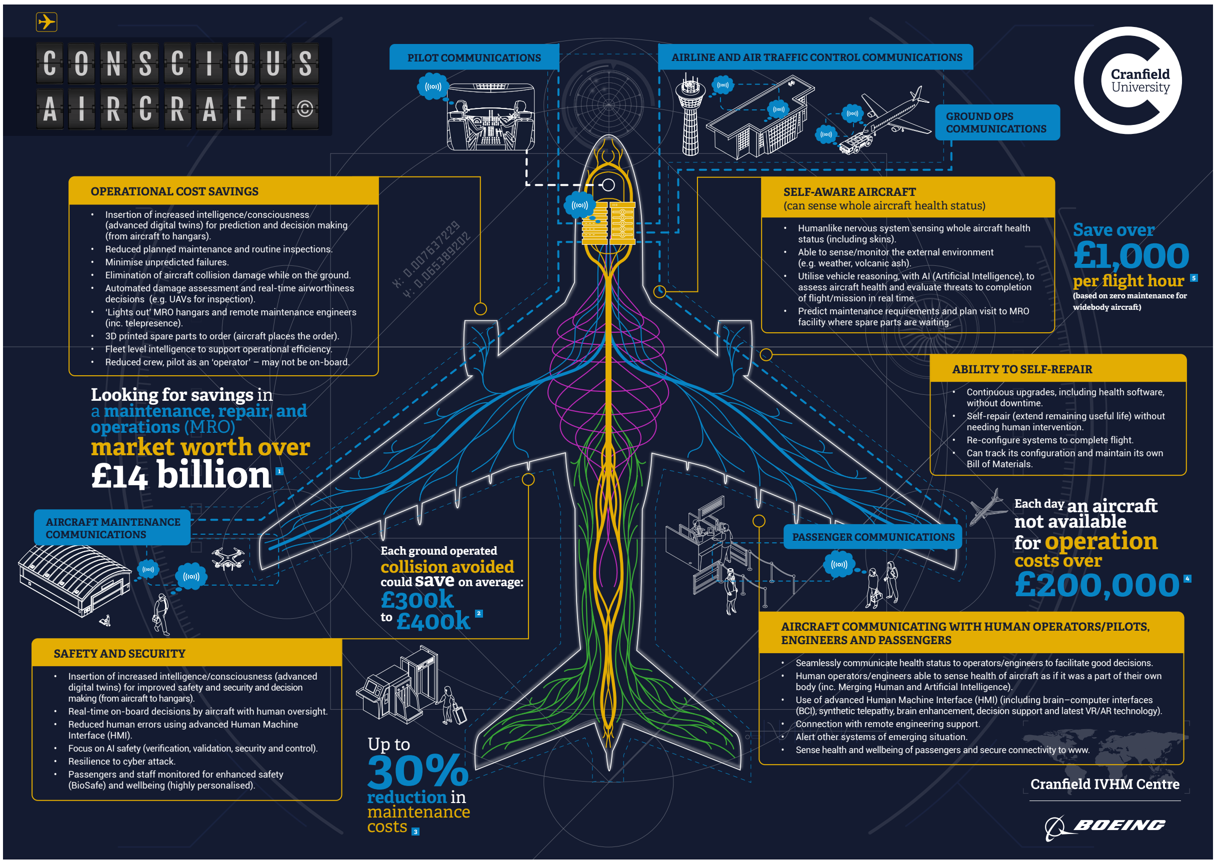
[65]www.iata.org/whatwedo/workgroups/Documents/MCTF/AMC-Exec- Comment-FY14.pdf

[66]Dr Alexander Girous, London School of Economics, Sky High Economics: Chapter Two: Evaluating the economic benefits, 2018.

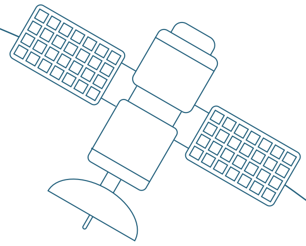
The Conscious Aircraft principle uses sensing and communication technologies to increase awareness that removes risk and unnecessary costs: avoiding problems caused by component degradation, unpredicted technical failures and human error. With the reduced need for routine, planned maintenance, as well as anticipating the potential for failures, maintenance costs for Conscious Aircraft would be cut by an estimated 30%[67].

The roadmap of research suggests a true Conscious Aircraft will be in service by 2040. Expected milestones along the route include the availability of a whole aircraft digital twin – a virtual replica of an aircraft based on a full range of sensor data – by 2023/4; a prototype of a digital twin with 'consciousness' – in other words, with reasoning capability – by 2026; a working ultra-low maintenance prototype aircraft by 2035. Technical roadblocks at this stage are around ensuring the resilience of the architecture and associated communications; developing the sophistication and safety of AI; and increasing the autonomy of robotics. Aside from the technology, there will also be the need for regulatory approval (demonstrating that autonomous systems for maintenance can be as safe as manual) and creating business models that fit the changing industry and market needs.

Figure 6



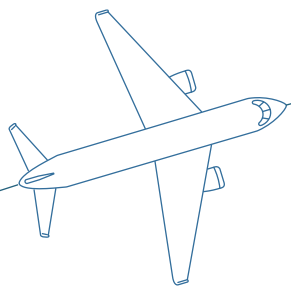
[67]Oliver Wyman, Global Fleet and Market Forecast 2020-2030, 11 February, 2020.



CONCLUSION

New aircraft-based technologies and standards are giving rise to both 'Connected Aircraft' and the 'Connected Cockpit' connected-anywhere concepts that have fully connected digital ecosystems enabled by multiple data links. These ecosystems feature secure, high-bandwidth satellite connectivity alongside a combination of radio and internet streaming (5G, LTE, Wi-Fi and commercial networks) transferring significant quantities of data (terabytes). The complexity and interoperability of future ecosystems is seen as a significant challenge for the technology providers, regulators and airlines. A future vision of an aircraft connected system network is presented where radio-based infrastructure and satellite-based communications systems support airport communications systems for advanced connected aircraft systems and surface movement guidance and control.

As a result of the rapidly increasing availability of aircraft technical performance data, Integrated Vehicle Health Management (IVHM) is transforming the use of aircraft sensors into information that can be used to support platform health management decisions. As a result, scheduled time-based maintenance is replaced by condition-based maintenance strategies, so reducing engineer time and costs. Looking further into the future, aircraft performance management towards 'Conscious Aircraft' concepts which, through self-sensing and monitoring of a system's components, can either suggest appropriate maintenance actions or take action itself, so creating the potential for a zero-maintenance aircraft platform.



4. AIRLINE OPERATIONS – RECOVERING FROM THE PANDEMIC AND BEYOND

The impact of the COVID-19 pandemic and subsequent travel restrictions have had a major destabilising effect on aviation and caused great uncertainty across all areas of the industry. The only certainty is that the old roadmap for airline operations has been seriously undermined; models for the immediate recovery period and for building for the future need to be based on a host of new factors in terms of business realities, health regulations and consumer demands. These models are likely to be different for different airline business models.

In the current recovery period, the airlines are addressing the integration of bio-safe and COVID-19 protocols within their existing operations. An example includes requirements for enhanced sanitation procedures to clean and disinfect the aircraft between each flight. This can be conducted using traditional liquid- and aerosol-based disinfectants, as well as now cleaning with UV-C light (200 to 280nm wavelength), as previously has been used in hospitals, air and water filters, microbiology labs, and other applications[68]. Regardless of the approach taken, these processes can add time to the turnaround of an aircraft and can negatively impact on flight schedules.

The pandemic has shown that airline business models become increasingly unsustainable when demand falls well below the capacity offered in the market. An estimated 50% of airline costs are fixed or semi-fixed[69], so that high operating costs (for fuel, crew, airport and service charges) mean small profit margins even when airlines are operating at full capacity. Globally there were 2.2 billion fewer airline passengers in 2021 compared with 2019 and a reduction of 40% in the number of seats offered by the sector[70]. During 2020, in Europe 51% of aircraft were grounded at the end of 2020, intra-European traffic over the year was down by 54% and European traffic with the rest of the world by 59%. For 2021, the number of European flights were down by 44% with an estimated 1.4 to 1.5 billion fewer passengers[71]. Similar declines in traffic were witnessed in Asia (38%), North America (17%) and other key markets over this period[72]. These impacts have been felt equally harshly by low-cost carriers (who saw a 62% reduction in traffic in Europe) and scheduled network carriers (59% reduction in traffic) suffering large declines in traffic. At best, aircraft in 2021 were operating with load factors of between only 50 to 60%.

An IATA sample of major airlines highlights that with a forecasted drop in revenue of 54% in 2021 versus 2019, the impact on sector employment is significant. An estimated reduction of 21% in direct aviation employment has or is occurring representing a loss of 2.3 million jobs (340,000 within the airline sector alone). These numbers, while significant, are just a fraction of those jobs which the aviation sector supports in tourism, commerce, etc. Globally, the indirect job losses are estimated as being 44 million with Asia accounting for 27 million alone[73]. While some governments have provided selected airlines with 'life support' finances, airline failures have been continuing throughout 2021 with up to 16 further bankruptcies reported as of December[74].

It is clear that COVID-19 has changed the nature of the psychology of travel that extends beyond the pandemic itself; new home working practices, fresh thinking (including activism and awareness) around climate change, sustainability and greater corporate social responsibility are all now very much part of passenger decision-making. The rise and growing acceptance of the 'Zoom work culture', homeworking and teleworking, for example, raises important questions about the future demand for aviation business travel, which has often formed a stronger, more reliable source of

[68] https://www.aero-mag.com/honeywell-ultraviolet-cleaning-airlines-11062020/
[69] https://www.airlineratings.com/news/iata-warn-catastrophic-airline-job-losses-2021/
[70] https://www.icao.int/sustainability/Documents/COVID-19/ICAO_Coronavirus_Econ_Impact.pdf
[71] https://www.eurocontrol.int/sites/default/files/2022-01/eurocontrol-think-paper-15-2021-review-2022-outlook_0.pdf
[72] https://data.icao.int/coVID-19/operational.htm
[73] https://aviationbenefits.org/media/167482/abbb21_factsheet_covid19-1.pdf
[74] https://allplane.tv/blog/2021/2/11/2021-airline-bankruptcy-list-now-open

revenue for airlines than leisure travel. Future airline operations planning will need to reflect a shift to less frequent but longer, more clustered business trips by travelling executives.

A key factor in the recovery will be restoring passenger confidence both in terms of personal safety while in the airport, on board and at their destination, but also in terms of the ease and practicality of travelling. Air travel has to be made part of the 'new normal' – safe, workable, convenient. The challenge to date has been the unpredictability of the pandemic particularly with the arrival of new virus mutations 'of concern'. The 2021 Inmarsat Passenger Confidence Tracker[75] highlights passenger concern regarding COVID-19 is still high, although slightly less than 2020 (for example, 51% rate quarantining as their main travel worry, down from 60% in 2020). Greater certainty and predictability will play an important role in restoring passenger confidence in air travel in the coming months and years.

An all-important underpinning for building confidence and trust among passengers is real-time communications. Digital connectivity with passengers makes it easier to provide tailored information as situations change, to keep passengers informed of timings, as well as access to latest information on staying safe and local differences in the regulations and requirements of countries that passengers are travelling to[76]. IATA's research among passengers has found that: 82% want flight status information while they are on board; 50% would use onboard digital connectivity for shopping; 40% want connecting flight information; 37% want to be able to plan transport and accommodation for their onward trip; 33% to complete administration, such as immigration forms, digitally[77]. A 2018 survey suggested 67% of passengers were more likely to show loyalty to a particular airline if it offered high-quality Wi-Fi[78] . Expectations are likely to grow rapidly as passengers begin to assume an unbroken status as a digital consumer inflight.

ADDRESSING COVID-19 HEALTH SECURITY: THE TRUSTED TRAVELLER

The pandemic has highlighted the need for a means by which passengers' health situations can be verified throughout their journey. The industry has settled on a passenger's smartphone as the appropriate device to carry this information – validating a passenger's identity, authenticating their COVID-19 (or other) test results and vaccination details. Early in the pandemic many companies and government agencies developed their own add-on to their app or separate app[79], which led to the development of the CommonPass (SkyTeam members[80]). Other 'passport' or travel passes emerged, including the IATA Travel Pass, with Singapore being amongst the first to accept it as a valid form of COVID-19 status certification for country entry[81]. The key issue for future development is not the technology, per se, but rather commonly adopted protocols and common verification for such an app to be accepted on an 'end to end passenger journey' wherever a passenger may be travelling in the world. Currently this is not possible as passengers may need to aggregate information from multiple sources (e.g. Passenger Locator Forms [used by local public health authorities

[75] https://www.inmarsat.com/en/insights/aviation/2021/passenger-confidence-tracker-2021.html
[76] MPAA. (2018). 2018 Theme Report: A comprehensive analysis and survey of the theatrical and home entertainment market environment (THEME) for 2018. https://www.mpaa.org/wp-content/up- loads/2019/03/MPAA-THEME-Report-2018.pdf
[77] https://www.iata.org/publications/store/ Documents/GPS-2018%20Highlights.pdf
[78] Inmarsat Aviation. (2018). In Flight Connectivity Survey. https://www.inmarsat.com/aviation/com- mercial-aviation/in-flight-connectivity-survey/
[79] https://www.gartner.com/smarterwithgartner/5-trends-drive-the-gartner-hype-cycle-for-emerging-technologies-2020/
[80] https://www.healthcaredive.com/news/5-major-airlines-to-roll-out-digital-health-passport-for-travelers-next-mon/589810/
[81] https://www.futuretravelexperience.com/2021/04/iatas-digital-health-passport-paves-the-way-to-a-new-biometric-identity-for-travel/

and governments to facilitate contact tracing], PCR and lateral flow tests, etc) and present these data as separate sources of information. Where local rules may have recently changed, where language translations are poor, or perhaps where passengers are not technically adept in using their smartphones (for example, elderly passengers who have recently purchased smartphones for the express purpose of using a health passport app for travel) errors and delays at check-in and at the gate are likely. For this to be achieved, the industry (IATA, ACI and ICAO) and national governments need to work towards a solution that allows the traveller to use the same app that enables them to pass through the airport during their business trips or vacations but also provides access for a restaurant/theatre/sports event, etc.

AIRPORT SECURITY

Security and threat management in aviation will be enhanced by smart CCTV and sensors, making use of facial recognition technology to identify passengers in real-time. In combination, the smart systems can be used to detect abnormal behaviour within the airport: passengers circling around the airport; staying for unusual amounts of time in one area; showing an unusual walking pace or direction; or other kinds of suspicious activity, such as wearing a bulky coat in a hot climate.

While physical security checkpoints will still be needed, passengers are likely to be able to progress through 'open' gateways at a walking pace. 'Walk-through' screening has been made possible by an evolution in both existing screening technologies (such as computed tomography [CT] scanners) and more radical 3D scanning approaches that allow for material discrimination, high rates of detection and low levels of false alarms; and by advances in predictive analytics using artificial intelligence, computer vision and machine learning.

OPERATIONAL AGILITY THROUGH DIGITALISATION – ESSENTIAL FOR SURVIVAL

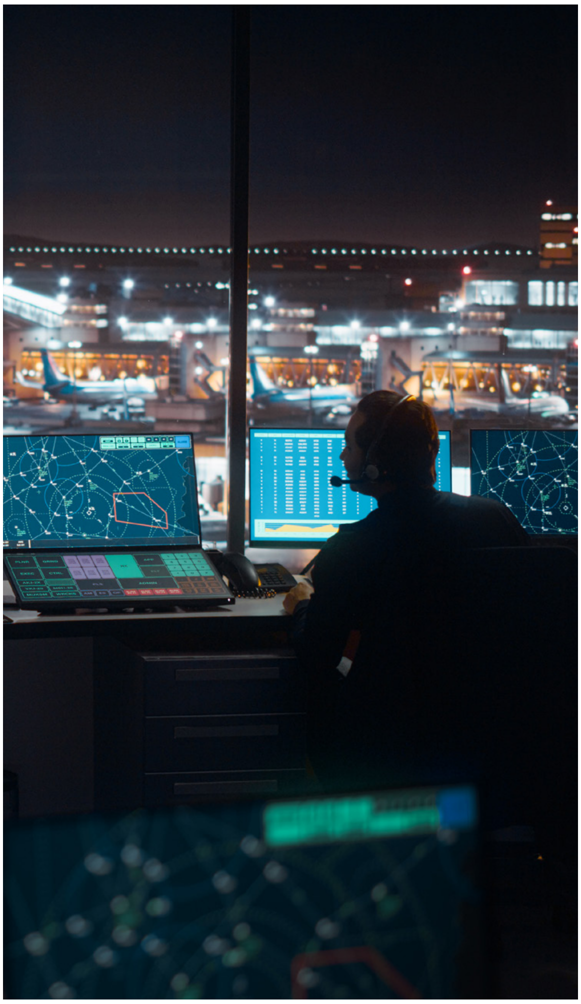
Traditionally, forecasting and planning activities in air transport have been undertaken almost exclusively on the basis of existing and historical data, as opposed to near or real-time information. The disruption of the past two years has severely challenged the relevance and value of these established, more traditional approaches to planning. During the pandemic, changing travel restrictions meant that airlines had to quickly plan and adapt to often rapidly evolving market conditions. In the recovery phase, while the rollout of vaccination programmes in some countries has meant the situation is more stable than it was, there is still likely to be a need for agile and flexible airline business operations. Digitalisation can play a key role in this process, with big data, predictive analytics, and advanced AI all having an important part to play in an airline's arsenal for forecasting and agile network planning. The ongoing partnership between KLM and the Boston Consulting Group (BCG) has showed how the application of machine learning and advanced optimisation processes can potentially provide significant cost reductions. BCG claim to reduce KLM's non-performance costs by up to 30% when the full suite of optimisers is implemented[82]. These include using machine learning to calculate optimal trade-offs between operational and cost aspects of airline performance, as well as less tangible aspects like the impacts of these decisions on customer satisfaction.

Indeed, while forecasting was once the preserve of analysing historical data and trends, real-time forecasting and decision-making have become the new imperative. Making agility the basis of operations requires a significant shift in the mindset and corporate culture of aviation management – as it would with the adoption of any disruptive technology. Fundamentally there

[82]https://www.bcg.com/en-gb/industries/travel-tourism/airline-industry/optimizing-digitizing-airline-operationss

needs to be a re-focusing away from the emphasis on the need for accurate forecasting and prediction – which we now know is of little use at times of major disruption – towards resilience and adaptability.

Aside from the immediate challenges presented by a global virus and its variants, the future will be increasingly volatile, dynamic and unpredictable. All businesses need to actively recognise and embrace the fact that shocks will happen, whether these are from climate change, terrorist activity, geopolitical instability, radical shifts in public opinion and activism, or more unforeseeable crises. Airlines will have to be flexible and agile if they are to survive. They will need to break down traditional business silos and use digital enterprise platforms that provide accessible stakeholder collaboration tools that support new multi-disciplinary teams able to dynamically react to changing business environments[83]. The success of airlines will be based more on continuity, adaptability and change management as part of a broader collaborative and just airline culture, rather than any ability among their planners to 'predict and provide'.



Technology has a key role to play in enabling airlines to manage the complexities that come along with building agility and elasticity into planning systems. The combination of advanced data capture, analytics and decision-making capabilities makes it possible for more information to be gathered from across airspace and airline operations in real-time – delivering the big picture view that makes flexibility viable, based on a knowledge of the full impact of changes. This has important applications for disruption management, especially for airports that are congested or traditionally operate close to capacity. This is especially important in the context of climate adaptation and resilience planning, and the increasing role climate change and extreme weather events are having on air transport. Given the level of complexity, AI, automation and machine learning capabilities will be important in providing automated decision-making in real-time to alleviate problems in areas such as scheduling and route network planning before they occur.

The use of digital twins alongside the Internet of Things will offer airlines a 'living' digital representation of assets – a model that can be used to explore the impact of changes to systems before putting them into practice; to anticipate the effects of disruptions from both known and unexpected events. In this way the digital twin for airline operations has the potential for a step change in how air transport is operated, reducing the risk and costs involved both in delivering change and managing unpredictability.

[83]https://www.dataiku.com/stories/etihad-airways/

CONNECTED TECHNOLOGIES ENABLING ENVIRONMENTAL SUSTAINABILITY

Digitalisation and digital transformation play an important role in tackling aviation's environmental externalities at almost all stages of the door-to-door journey, and at the same time help create more robust airline business models.

With aviation considered to contribute upwards of 2% of global CO2 emissions, one of the key areas of focus for reducing fuel burn (and thus emissions) is optimising flight profiles. In some cases, the shortest and most efficient flight profile and aircraft routings are difficult to achieve due to airspace and air traffic regimes. In other cases, especially in congested airspace, aircraft may have to burn extra fuel waiting in holding patterns (or stacks) while waiting to land. All of these aspects contribute to excess fuel burn which has financial and environmental implications for the operator. Traditionally, manual methods of flagging fuel-saving opportunities at a route level were based on a range of conditions and criteria being met before any action could be taken by the flight crew. Fuel saving opportunities were identified by analysis in an operations room post-flight.

With new platforms of digital connectivity, data from Flight Data Recorders, operational flight plans, ACARS and payload can now be combined with environmental data (weather conditions and air traffic control constraints) to make decisions about how to best optimise aircraft routing and fuel uptake. This process can be achieved on the ground before a flight but also, increasingly, in real-time by pilots and flight crew using EFB (Electronic Flight Bag) applications that allow for inflight optimisation: automatically alerting a pilot if there is a fuel-saving opportunity during a flight, and detailing how to take advantage of that opportunity. Pilots and flight crew are engaged directly in the process of fuel saving, receiving near instant alerts and feedback which improves flight crew engagement in the process of fuel saving. An example of a system already in operation is SkyBreathe, adopted by Air France in July 2020 as part of its objective of reducing CO2 emissions per passenger/kilometre by 50% by 2030 (compared with 2005). SkyBreathe uses artificial intelligence, machine learning and big data algorithms to automatically process billions of data records to identify saving opportunities and recommend actions expected to reduce total fuel consumption by 5%[84].

In the longer term, new design concepts and sustainable forms of propulsion (namely hydrogen and electric/hybrid electric power) have the potential to dramatically reduce emissions at source. While these new concepts are initially likely to be limited to shorter-range applications, as battery technology and advances in energy storage develop, low or zero emissions aircraft over longer ranges may become a reality in the coming decades. In the shorter-term, incremental improvements in airframe aerodynamics, advanced materials, and engine technology are likely to be the extent to which technological advances can improve fuel burn and limit emissions from existing aircraft types.

THE CONNECTED JOURNEY – DIGITAL CUSTOMER SERVICE ENHANCEMENT

The connected journey, and the benefits it brings, doesn't stop at the gate but extends across the entire door-to-door journey. The COVID-19 pandemic has forced a rethink of what customer care means. The ability of airport operators to monitor, predict and influence passenger movements and behaviour both door-to-door and within the airport was already a key trend before COVID-19, but now the need is greater and more urgent. In addition to traditional satisfaction metrics, additional priorities and a much greater focus on safeguarding passenger health and wellbeing are key aspects of the needs and priorities of air passengers in the post pandemic era.

With knowledge of passenger location provided through a smartphone app, airlines can provide

[84]https://corporate.airfrance.com/en/press-release/air-france-chooses-skybreather-eco-flying-solution-reduce-fuel-burn-and-co2-emissions

door-to-door support and improve experience: through information on road traffic and other transport options and offers; updated boarding times and time-to-gate; directions to lounges, services and available deals; both areas of congestion and quieter spaces; as well as any gate-change and delay notifications. The Star Alliance Connection Service as used by Singapore Airlines, for example, provides customised airport wayfinding information directly to passengers' mobile phones[85]. Unavoidable (largely weather related) journey disruptions, that have always been extremely difficult or impossible to predict with accuracy, can be better managed. Faster resolution of disruption, along with greater transparency in the information passengers receive, helps to generate trust and confidence. Typically passengers would be notified of a cancellation or disruption with more prior notice, so allowing the airline to be in a position to be more flexible and set out a tailored re-accommodation plan according to the evolving situation and their policy guidelines: compensating or rewarding passengers in the form of lounge access, frequent flyer points or vouchers, or finding a resolution via booking on an earlier flight, rebooking with a partner airline, or a stay in a hotel. The options can be 'pushed' to the passenger to allow them a choice of options, including easier access to rebooking when there are cancellations.

For airlines and service providers, more adaptable systems such as these should lead to lower costs from disruption, and less damage to customer satisfaction and loyalty. When used as a shared platform, the greater visibility and saving of data involved will also benefit travel partners, hotels, airport operators and local transport providers, who can also plan accordingly in terms of resource allocation and inventories; other airlines can be alerted to potential additional demand.

The ability to track and locate passengers in real-time through an airport will also have important implications in terms of reducing delays. Where a passenger is lost or failed to notice that they are late for boarding their flight, it will be possible to identify the location of the passenger within the airport. Virtual queuing exercises, for example, where passengers receive a time 'slot' for check-in and going through airport security, could be pre-booked – or sold – to passengers, helping to alleviate queues forming at peak times. These slots can be adjusted in real-time based on changing arrival patterns, security lane processing times or other factors. As a result, passengers have more time to spend in less congested areas where there are food, beverage and retail outlets. For these approaches to work effectively, a mix of advanced data capture, analytics and decision-making capabilities will be needed: cameras and other sensor-based technologies to determine passenger flow, densities, and behaviour. Trials where passengers were boarded by seat number were conducted at Gatwick Airport in the UK in 2019, leading to a 10% saving in boarding time[86]. Following a successful trial in 2020, the 'SEA Spot Saver' programme[87] has now been rolled out in full at Seattle-Tacoma

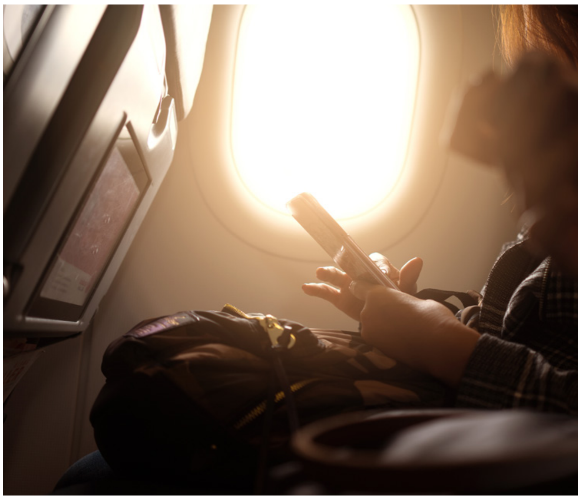
[85] https://www.singaporeair.com/de_DE/at/media-centre/press-release/article/?q=en_UK/2020/October-December/jr0820-201005
[86] https://www.bbc.co.uk/news/business-50214631
[87] https://www.portseattle.org/SEAspotsaver

airport in the US. This allows all passengers the opportunity to pre-book a time to pass through security before travelling, or to enrol in the queue using a QR code upon arrival at the airport. The identification and exploitation of these types of 'win-win' opportunities will be central to future passenger experience and aviation industry business models. For more than six years, Helsinki Airport has been using a system of Wi-Fi and sensors to prevent long queues and bottlenecks[88]. Miami has a network of 400 Bluetooth beacons to send personalised information and services to passengers in terminals, gate walk times, retail deals and flight updates[89].

When integrated with smart automated decision-making systems, the potential for enhanced prioritisation and safeguarding increases. For example, an expected congregation of passengers arriving from a high risk destination could trigger decisions to open additional baggage reclaim belts to create more space. Similarly, based on information on customer needs, autonomous robots can be deployed and positioned to provide passenger flight information, directions or mobility services for passengers looking for help in moving around the airport.

THE FUTURE OF INFLIGHT ENTERTAINMENT AND IN-CABIN SERVICES

The provision of in-cabin services, including Inflight Entertainment (IFE), will equally be enhanced through greater digital connectivity, significantly improving both passenger and crew experience. Leveraging IoT based sensor data and trend analytics, a more customer-centric approach to service provision can be implemented, providing seamlessly integrated connected experience from origin to destination. Valuable data throughout the experience can help gain insight into the efficiency of the services, allowing them to be validated and refined in real-time. A better-connected cabin with personalised services would significantly enhance passenger experience and thus facilitate airline loyalty. In our digital age, predictable, resilient, and seamless connectivity has become fundamental and actually expected in all forms of life. A better and more personalised travel experience could be provided to passengers that specifically addresses their individual needs and preferences, based on the available data. However, the adoption rate of these next generation systems will depend on the market segment in which the airlines operate and their associated business models.



Most Low Cost Carriers (LCCs), historically, have not offered IFE systems, principally for cost reasons. They do, however, have a long history of charging for additional and ancillary services, and therefore it is likely that these airlines would consider adopting new connectivity services if they can more than cover the cost of installation and service by charging passengers who wish to use it. Here the variables that will affect adoption will be flight length (the longer a flight the more likely passengers may wish to access network services), and price sensitivity (LCC passengers tend to be more price-focused than network carrier passengers). For some LCCs, especially those offering longer sector lengths (e.g. AirAsia X and Scoot) network connectivity may provide a means of enhancing product offering, and getting passengers to pay for it.

During the COVID-19 pandemic, airlines have been aiming to reduce cost as quickly as possible and that includes retiring older aircraft earlier than intended – this means that re-fleeting will provide opportunity for airlines to incorporate inflight connectivity infrastructure

[88] https://www.flightglobal.com/analysis-how-airports-are-looking-to-new-technologies/115063.article

[89] https://www.futureairport.com/features/featurebeacon-technology-for-airport-mobile-apps-6199220/

at delivery, with long range narrow-bodied aircraft (like the A321LR) potential early adopters of connectivity services offerings to passengers flying longer sectors. Whether re-fleeting with new aircraft or undertaking fleet conversions, high bandwidth digital connectivity presents airlines with strategic choices. Most passengers 'bring your own' (BYO) smartphones or tablet devices on board and many choose to consume pre-loaded content inflight rather than use a carrier's inflight entertainment system's content; this is particularly so for younger travellers. Airlines must decide whether to continue to offer dedicated inflight entertainment systems which add significant weight to the aircraft (in excess of 1000 kg across a A380), require ongoing maintenance, incur media licence costs and often create issues for crew if a system is not working and passengers cannot be re-seated.

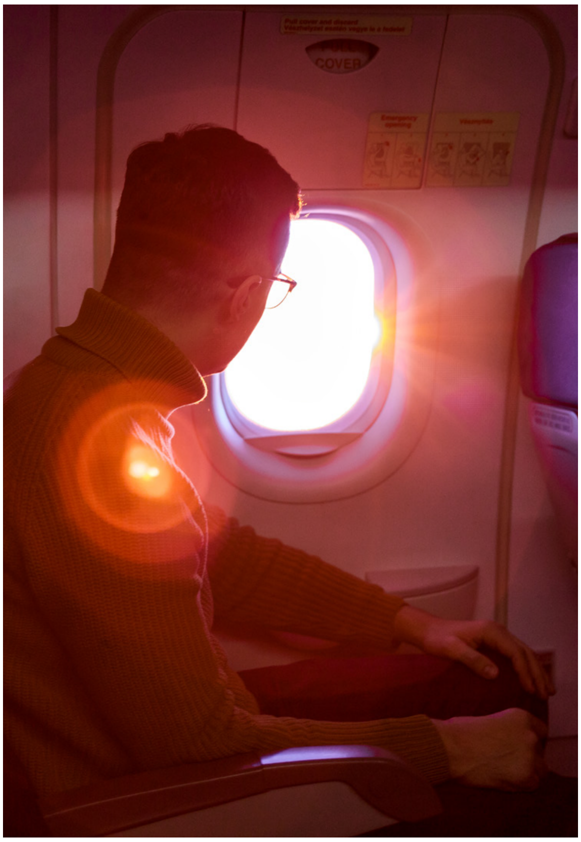
The alternative for airlines is to offer network connectivity to BYO devices. The number of airlines seeing an increase in uptake of connectivity packages has increased in recent years. This is particularly for those airlines that cater for business travellers where the take-up rate is higher, perhaps as business travellers may be able to expense connectivity fees. For leisure passengers, the decision to take up a connectivity package will, of course, depend on cost, usability (network reliability), and the number of people in a family group looking to take up a service. For parents looking to distract young family members, connectivity might present a good value offer depending on the type of access. For many families, BYO devices that are pre-loaded may continue to be a lower cost means of entertaining members of their party. Large network carriers, however, use their product offering and quality of customer experience to compete with one another. The history of product development in this sector has seen network carriers escalate the quality of product to attract customers. This is especially so in premium cabins. Greater legroom, lay-flat beds, inflight entertainment systems, and enhanced catering have all been used to try to create unique selling propositions to their customers. These iterations in service enhancements have seen costs rise for all carriers competing against each other, for unsustainable revenue premiums. Inflight broadband connectivity provides another service enhancement that may be difficult to charge customers for but may be a necessary addition to benchmark against other carriers that have also added connectivity. For these carriers, removing IFE sets and substituting this with inflight connectivity maybe seen as a retrograde dilution in service quality, although it may be promoted as an evolution in product that enhances the environmental damage the flight produces. Whilst connectivity may be attractive to business class passengers who can maintain contact with their company inflight, the removal of other IFE sets is unlikely (esp. for the carriers that compete with the Middle Eastern carriers that have remarkable inflight products).

Sensors embedded in cabin seats could read anxiety levels, hydration and temperature, and notify the crew or change the cabin environment to make it more comfortable. Connecting flight notifications could be sent directly to passengers' smartphones, providing directions to the departure gate and an estimate of how long is needed to get there, whilst at the same time the airline could be informed that passengers are on their way to ensure they don't shut the door prematurely or, if necessary, rebooking them onto alternative connecting flights. Allowing passengers to pre-book meals and onboard services in advance of travel was a measure introduced by airlines to minimise onboard interactions during the COVID-19 pandemic[90] which in turn reduced food waste and cost. However, these efficiency gains also have an important implication in terms of reducing weight on board the aircraft, and thus the amount of fuel uplifted to transport these items in the cabin. While these may represent only fractional gains at an individual flight level, when aggregated across on entire network over a period of time, the benefits of such systems can be substantial.

Cabin crews can also benefit from new analytical processes that allow a better understanding of their aircraft and cabins. The provision of more efficient tools, with real-time feedback on processes, cabin resources' health status and customer satisfaction will all facilitate a better understanding of the working cabin environment and thus improve the overall crew's work experience. Digitally enabled smart devices will allow crews to monitor and operate all of the cabin connected ecosystem more efficiently, from the galleys to the bins, emergency equipment, cargo and lavatories, with any issues such as food availability and bathroom shortages quickly being identified. Such smart processes have been already deployed by airlines such as KLM, Etihad Airways and Condor Airlines[91], amongst others, to improve overall cabin service reliability, quality and performance on board, with full transparency of inventory management for efficient operations. Real-time and historical data will inform the crew if passengers experienced a disruption on a connecting flight, their food and beverage preferences, even their preferred hotel or rental car chain, all of which can be used to offer more of a personalised, luxury experience.

MONETISATION OF DIGITAL SERVICES

It is clear that the level of access to onboard digital connectivity may become an intended point of differential for some airlines. For example, Delta Airlines is upgrading its narrowbody aircraft (new and retrofit) to offer 'full, fast and free connectivity' – home-like Wi-Fi connectivity – so it is approaching connectivity as a necessary utility for its passengers. For other airlines this level of offer is not part of their strategy. Virgin Atlantic, for example, is charging for access in the belief that the tipping point from a small number of high paying passengers to access connectivity to a large number of more price sensitive customers is being reached. There is the belief though that the fact that connectivity will soon become a necessary 'utility' for all passengers will drive all airlines towards having to offer a service.



[90]https://www.singaporeair.com/en_UK/sg/travel-info/covid19-measures/

[91]https://www.futuretravelexperience.com/2020/11/5-inflight-trends-resulting-from-covid-19-that-can-optimise-the-onboard-experience-reduce-costs-and-empower-crew/

[92]https://www.businesstraveller.com/business-travel/2021/06/25/singapore-airlines-launches-ife-e-shopping-service/

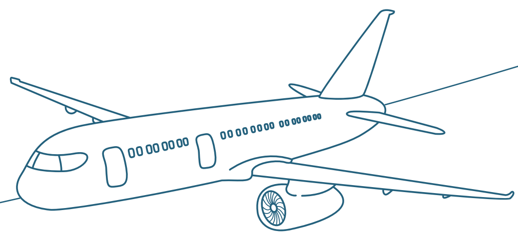
Whilst network connectivity can be potentially provided as a free service to airline passengers, there are a number of ways this connectivity can be monetised. For most airlines, a portfolio of revenue streams will be required to defray the cost of service provision. The most obvious one is to charge passengers to use the service, based on units of data consumed, time connected, or the type of connection allowed (messaging, surfing, streaming). For connections through an IFE system the opportunity to charge will be reduced, as travellers have access to licensed content for free via the system. For direct connectivity using a BYO device, a connectivity app or platform can provide a number of revenue opportunities for the airline by providing additional services to passengers and bringing customers and third parties together in various ways.

One of the main opportunities for the airline is providing a retail experience through the platform with duty free being a significant opportunity. The concept here is that travellers are more likely to buy from an online retail offer than from a trolley service on board. The purchases can then be delivered on arrival or sent to the passengers' homes. Singapore Airlines, for example, launched their IFE e-shopping service in June 2021 on selected A350 aircraft[92] allowing customers to make duty free purchases and receive delivery on their next SIA flight or at their homes.

Complementing direct charging and retail models are clickable on-screen adverts that can be laid over content such as an inflight map. Airlines may opt to substitute their inflight magazine with free access to passengers through the platform, and the airline can then sell advertising space in the online magazine. Similarly, destination hospitality providers can offer content for free on the device with special offers and purchase opportunities throughout the content. Destination specific infomercials can offer value to passengers looking to enhance their trips by booking airport transit services, tourist attractions, and access to hotel upgrades, etc.

Airlines can also earn revenue from providing access to third-party services, as passengers would be prepared to pay a fee to gain access to their subscription entertainment services, such as Netflix, Amazon Prime, or Apple Music, Spotify, etc. via a connectivity platform. The platform becomes a means by which passengers are offered access to connectivity packages, followed by content with contextualised advertising, personalised for the interests of the passenger, retail opportunities for duty free, food and beverages, click though adverts for destination tours, access to free content (e.g. Apple Music, Netflix) with a view to subscription sign ups and destination and airport connection information.

Finally, access to specific content can be sponsored by a third party. Subscription entertainment services may be prepared to sponsor access to a limited amount of content for free, or, should the passenger sign up inflight for a trial period, gain access to full content on that subscription service. For example, American Airlines has recently begun promoting free access to Apple Music on board. Apple Music's strategy in the sponsorship is to build paid subscriptions



[92]https://www.businesstraveller.com/business-travel/2021/06/25/singapore-air-lines-launches-ife-e-shopping-service/

CONCLUSION

The pandemic and the concern over climate change has changed society's attitude towards air travel, and is causing both airports and airlines to reconsider their service offerings and business models. Increased biosafety awareness has accelerated the introduction of a variety of new digital technologies including; 'health passports' or travel passes, touchless identity screening, virtual queuing and airport flow management, that together are enabling safe, seamless movement through airports by reducing contact points, increasing border bio security and so seeking to restore passenger confidence in travel. By whatever means, it is recognised that air travel needs to be made safe, workable and convenient, and, most of all, airlines and airports, with their supply chains and collaborators, will need to be able to adapt rapidly to changing market needs. Airlines in particular will need to be more flexible and agile than they have been in the past if they are to survive inevitable new shocks.

Enhanced digital connectivity is enabling the concept of a 'connected journey' to become possible through creating more efficient and personalised wayfinding through airports, more intelligent and responsive baggage tracking and real-time updates on the condition and progress of cargo in transit. Passengers are, moreover, requesting that they are better informed of unavoidable weather-related disruptions and that alternative personalised travel arrangements are made available to them in a timely manner, and digitally.

Inflight, passengers and crew now expect the same levels of personal digital connectivity as they experience in their everyday lives. Digital IFE services, for example, that were once only provided by the premium long-haul carriers, are now having to be considered by the low-cost carriers. Providing seamless connectivity to passengers' own tablets and smartphones ('bring your own') is seen as a means of avoiding costly and heavy aircraft upgrades, and potentially introducing new IFE service revenue streams through subscription or third-party advertising for the low-cost carriers. Beyond IFE, new digital services could support a greater sensing of individual passenger wellbeing (e.g. anxiety levels) and service satisfaction, provide individual onward travel information, support onboard virtual queueing for toilets, and meal distribution. The overall effect would be to provide an enhanced and, most importantly, personal inflight service. Various options to monetise passenger connectivity services are being considered and will be essential to defray additional launch and operational costs. Ranging from simple time-charged data access to online retail purchasing from the trolley service, access to subscription entertainment services and clickable third-party advertising from destination providers (hotels, tourist attractions, etc.), it is anticipated that the commercial viability of these services will regulate the pace of adoption within the sector.

5. AIRSPACE OPERATIONS – NEW CHALLENGES AND NEW OPPORTUNITIES

Prior to the onset of the COVID-19 pandemic the pressures of global airspace congestion were already being seen and felt. Average delays, both on departure and arrivals, reached 20 minutes per flight in peak summer months and 10 minutes in winter[93]. The so-called 'capacity crunch' affects both airports and the wider network. Without transformative action, airports were expected to be unable to accommodate the forecast 1.5 million flights in 2040, equivalent to around 160 million passengers being unable to fly[94].

COVID-19 has altered this picture, although only temporarily. The global aviation system has a period of respite: an opportunity to prepare for the expected boom ahead. Modernisation of the system can take place without impacting workload, without needing to be rolled-out during the storms of unsustainable traffic levels.

For example, the aviation sector is currently heavily reliant on legacy technology such as VHF. The narrow frequency band (30-300MHz) of VHF makes it an unrealistic option for meeting the ever-expanding needs of the aviation industry. Evidence from Honeywell has suggested that VHF congestion at altitude means that an aircraft can hear up to 60 air/ground transmitters at any one time[95].

This means there is a potential window for the implementation of new but long-considered initiatives such as: Trajectory Based Operations (TBO) solutions; SWIM (System Wide Information Management), the shared platform for harmonising aeronautical, weather and flight information where both the air traffic management network and aircraft themselves are acting as nodes; and next-generation VHF that will be multi-channel, easily programmable software-defined radio.

Taking a grip on the 'capacity crunch' is fundamental to fulfilling the potential of new emerging markets and revenue streams in aviation. Inefficiencies in the current system prevent the full potential of new entrants, such as the use of Unmanned Aircraft Systems (UAS) in emergency services, environmental monitoring, construction, logistics, last-mile delivery and urban air mobility. It is estimated that by 2050 there will be over seven million UAS, of which 400,000 will be for commercial applications, all with differing types, sizes and performance characteristics, creating a significant challenge to their safe and seamless integration with manned aviation, particularly into controlled airspace[96].

THE FUTURE OF AIRSPACE OPERATIONS – AUTOMATION

Enabling and effectively managing air traffic growth – while at the same time mitigating its environmental impacts – will be dependent on transforming the existing air traffic management system and where possible the airspace structures themselves through the increased adoption of automation.

For existing flight systems, the industry as a whole needs to embrace the automation potential of TBO that will enable a digital transformation of the underlying infrastructure system. This will be made possible through significant increases in levels of connectivity, combining airspace configuration and design with technologies to decouple service provision from local infrastructure, and progressively increasing the levels of collaboration and automation support.

The progressive introduction of increasing levels of automation and common ATM data services, will allow the overall system to make use of physical infrastructure and human resources

[93]https://www.eurocontrol.int/sites/default/files/2020-06/eurocontrol-prr-2019.pdf
[94]https://www.sesarju.eu/masterplan2020
[95]https://aerospace.honeywell.com/en/learn/about-us/news/2020/01/cpdlc-issues-in-europe
[96]https://www.sesarju.eu/sites/default/files/documents/reports/European_Drones_Outlook_Study_2016.pdf

more efficiently, and to be able to respond to disruptions and changing demand with greater flexibility and resilience. Service-oriented architectures – that decouple vertically and geographically integrated services along with new technologies, such as virtual centres associated with a sector-independent Air Traffic Services (ATS), will allow for dynamic, optimised and shared management of airspace. Remote provision of ATS will mean that sectors can be dynamically modified based on demand and airspace availability and managed by the most appropriate area control centre. These advances will ensure that the future airspace is fully optimised for network-wide and cross-country air traffic flows, enabling its modernisation through dynamic airspace management and configuration mechanisms and maximum co-operation across Flight Information Regions[97,98]

GAINING EFFICIENCIES THROUGH SATELLITE-ENABLED REAL-TIME FLIGHT PLANNING

Current air traffic management is based on a fixed filed flight plan and tactical interventions by ATC as the flight progresses. While the current system has proven effective in the past, its lack of flexibility is having an impact on the overall capacity of available airspace. New alternatives such as TBO[99] will enable the ATM system to know and, where appropriate, modify the flight's planned and actual trajectory, before or during flight, based on accurate information that has been shared by all stakeholders. This will lead to efficiency gains for both individual aircraft and for the network as a whole, since it enables the flight to be managed as closely as possible to the airspace user's ideal profile, while optimising the flow of air traffic.

TBO calls for full integration of flight information in order to create a synchronised view of flight data by all actors involved, during all phases of flight from departure gate to arrival gate. This shared information also includes any constraints in airspace and airport capacity and those imposed by the various ATM stakeholders. TBO provides greater certainty of aircraft's forecasted positions both in the sky and on the ground, at all times, which in turn results in improved network predictability, safety, and flight optimisation. TBO allows resources to be more effectively planned and the use of airport and airspace capacity to be optimised. Finally, improved flight planning through TBO facilitates environmentally enhanced flight profiles to be implemented.

With TBO, aircraft will progress in four dimensions referred to as 4D (the three spatial dimensions plus time as the fourth), sharing accurate airborne predictions with the ground systems, and being able to meet time constraints at specific waypoints with high precision when the traffic density requires it. This will allow better sequencing of the traffic flows and facilitate so called 'green descents' to airport terminal areas. With a green descent (or Continuous Descent Operations) the aircraft descends continuously with near idle thrust, avoiding level-off as much as possible prior to the final approach, thereby using significantly less fuel.

By taking a holistic view of the trajectory from beginning to end, the TBO concept will enable airspace users to operate their preferred trajectory from gate-to-gate, in order to satisfy their business and operational needs; for example, through 4D trajectory optimisation during the planning and execution phases. TBO and 4D are enabled thanks to the sharing of the same aeronautical, weather and 4D trajectory information via ground-ground and air-ground SWIM[100] communications. TBO will bring increased predictability, enabling a reduction in buffers and optimisation of capacity and

[97] https://www.sesarju.eu/node/3697
[98] https://www.faa.gov/nextgen/media/NextGenAnnualReport-FiscalYear2020.pdf
[99] https://www.sesarju.eu/sesar-solutions/trajectory-based-operations
[100] https://www.eurocontrol.int/concept/system-wide-information-management

resources. Airspace configuration will be dynamically adjusted in response to capacity and demand needs, using fully developed civil-military collaboration.

In order to fully enable real-time sharing of 4D trajectories, timely access to airspace management data and information services is paramount. Network infrastructure should also be included that supports multi-link capability and seamless transferability between different data link systems such as satellite communications (Satcom), terrestrial datalink systems, and others in order to leverage as much as possible all technologies available, as proposed with Inmarsat's Orchestra, a global, multi-dimensional, dynamic mesh network of complementary technologies.

Flight planning takes account of multiple factors, ranging from aircraft status and operational requirements to traffic flow constraints and weather conditions. Using all possible data sources contributes to an improved prediction of the aircraft trajectory and to more efficient overall network operations. Trajectory prediction and management is a collaborative process that takes place between airspace users and air traffic control. New data link communications provide an opportunity for these actors to exchange more information in order to optimise the flight profile flown by each flight. High-capacity, satellite-based digital data links (such as the ESA-Inmarsat Iris programme) will be fundamental to carry text communications and 4D information between ATC and aircraft safely and seamlessly across the global ATM environment, both in continental and oceanic airspace, alleviating the existing saturation of voice communications.

Satellite-based digital data links will pave the way for ubiquitous Automatic Dependent Surveillance Contract – (ADS-C) functionality, that downlinks the Extended Projected Profile (EPP), a package of refined information on the projected trajectory from the airborne side, that includes up-to-date and accurate information from flight management system (4D prediction and speed schedule), and indicates the airspace user's preferred trajectory considering the real-time situation (e.g. effect from actual wind, weight and latest ATC instructions).

The European SESAR approach to 4D trajectory assumes that the aircraft has the best knowledge of its future trajectory and therefore the trajectory predicted by the Flight Management System (FMS) is the most accurate. Once the final Controlled Time of Arrival (CTA) constraint is agreed upon, the aircraft will meet it through the Required Time of Arrival (RTA) capability of the FMS. On the other hand, in the concept proposed within the USA's NextGen[101] programme, the ground system calculates the first CTA, uplinks it to the aircraft and starts the negotiation. This because it is assumed that the ground system has a better knowledge of the traffic, and therefore has a better situational awareness. After the CTA has been agreed upon, the aircraft will meet it using the RTA capabilities of the FMS.

TBO capabilities are being introduced in phases in order to ensure that the organisational changes needed from affected stakeholders are effectively managed to fully leverage the benefits of TBO. As part of the NextGen programme, initial TBO capabilities have already been deployed and assessed in specific geographic areas[102], with full capabilities being expected to be deployed in the next five years. The ESA Iris[103] programme has developed the adaptation of the SB-S Inmarsat product to meet the requirement of trajectory-based operations for the continental airspace. This capability is much needed in the crowded European airspace and is expected to deliver fuel savings to airlines with preferred route and profiles available to them. Iris is an essential enabler to trajectory-based operations as the current datalink technology (VHF Datalink - VDL2) is reaching its capacity limits. Iris is mature with a certified and operational service planned for 2023.

[101] https://www.faa.gov/nextgen/
[102] https://www.faa.gov/nextgen/media/NextGenAnnualReport-FiscalYear2020.pdf
[103] https://www.inmarsat.com/en/solutions-services/aviation/focus-on/iris.html

GROUND BASED SURVEILLANCE AND COMMUNICATIONS

Ground-based airspace surveillance is expected to be provided through contracted service providers working within an integrated digital framework. Surveillance and communications services will be delivered via contractual relationships between customers and providers, with clearly defined performance and quality targets – meaning new business opportunities for enterprises, and cost-savings and improvements in quality levels for customers as a result of the competition between providers.

The progressive introduction of a service-based approach to surveillance and communications infrastructure will make it possible to decouple the provision of ATM data services from specific agencies providing ATM. As a result, air navigation service providers will have more flexibility to choose how they provide their services. A service-based approach to surveillance and communication provides a strong incentive for the national service providers to co-operate across boundaries: fully leveraging the collaborative use of technologies, the geographical distribution of equipment, and, in turn, the use of the radio spectrum. This means there is the potential for a better platform and environment for integration of new services, such as space-based, automatic dependent surveillance broadcast (ADS-B), and satellite communications.

The performance-based service delivery approach will totally unlock the collaborative potential of the system. Existing operations are usually constrained by the way in which specific systems and technology deployments are being prescribed. Performance-based services specify the key performance targets that are to be met within a particular environment. This more open and collaborative model encourages technological and functional synergies, where communication, navigation and surveillance (CNS) operational needs, can all take advantage of common system and infrastructure capabilities across the ground, airborne and space segments.

Boundaries between different domains will disappear progressively as the infrastructure shifts to an integrated digital framework. Digital will be the most cost-effective solution for providers and users; technologies will evolve over time without the costs involved with making changes to the operations themselves as long as systems are meeting performance targets. Implementing a service orientated optimal mix of surveillance capabilities (from extant sources such as ADS-B, Wide Area Multilateration [WAM] and Mode S secondary radars) will make it possible to decommission all legacy systems (such as secondary surveillance radar [SSR] mode A/C ground stations).

ADS-B surveillance of aircraft enables improved surveillance data processing and distribution mechanisms to track aircraft during all phases of flight. It ensures compliance with new applications of ADS-B for radar airspace and airport surveillance, as well as emerging compliance requirements around security and enhanced airport safety nets: this includes data needed for Runway Status Lights, a fully automatic system based on Advanced Surface Movement Guidance and Control System (A-SMGCS) surveillance and associated operational procedures. In other words, improved monitoring of runways and taxiways to prevent runway incursions, accidents and the potential for collisions. According to IATA data, there is an average of 18 runway/taxiway incursions to commercial air transport aircraft worldwide per year[104].

Extending the ADS-B coverage that is typically limited by the Mode-S transponder of the aircraft, ADS-C is transmitted over the ACARS network via Satcom and is therefore not limited in range. ADS-C can operate either with CPDLC or independently on its own.

EMERGING DATA LINK SERVICES

Currently, most instructions issued by an air traffic controller to the pilot use voice communications and are limited to standard ICAO phraseology, which is not scalable and prevents the deployment of more efficient interactions that can reduce controller workload, increase capacity, and enable more optimised flight trajectories for airspace users. Voice

104https://www.iata.org/contentassets/7a5cd514de9c4c63ba0a7ac21547477a/rsar-1st-2015-final-version.pdf communication tasks represent between 35% and 50% of the executive controller's overall workload. Radio frequency congestion (at Airport Towers or Area Control Centres) is a well-known constraint, and at busy times it leads to high saturation of radio frequencies and prevents the optimisation of the overall capacity and thus its sustainable growth. Incorrect or incomplete controller-pilot communications are also the single most common cause of runway accidents (suggested to be 80% in NASA data)[105].

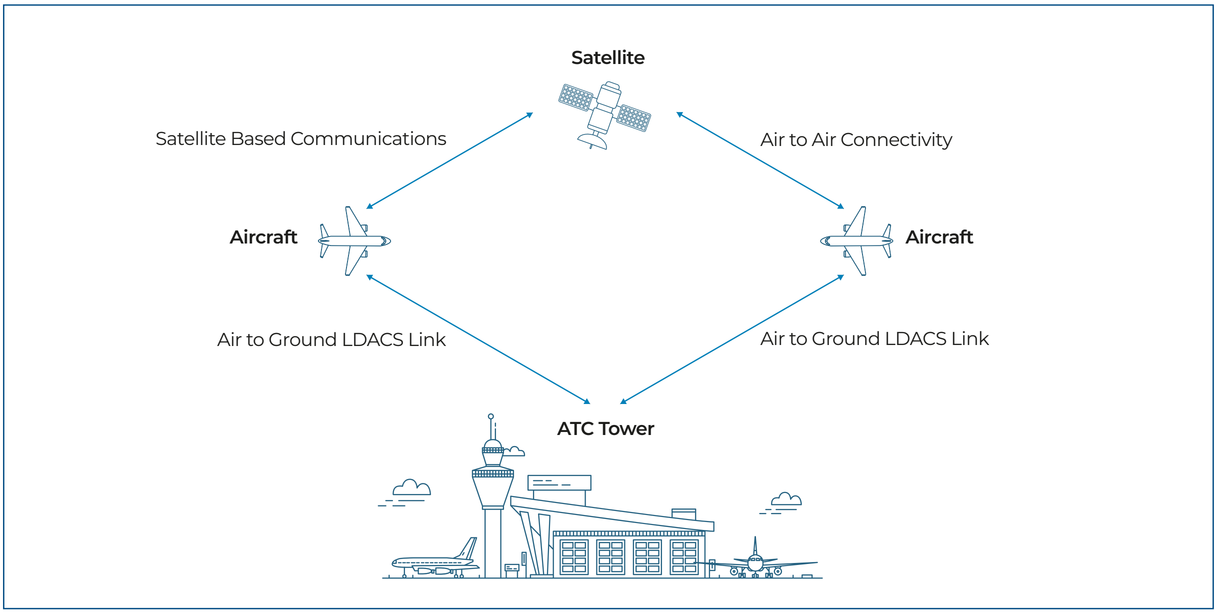
In order to effectively modernise the ATM ecosystem to accommodate future growth and to be able to cater for new future flight systems, the deployment of more aircraft-to-aircraft and ground-to-aircraft data link services and higher levels of automation are required to accelerate the implementation of silent and safe electronic communications and so reduce the dependence on voice-based protocols.

Early data link standards were developed under the Future Air Navigation System (FANS) umbrella, with Airbus and Boeing developing their own FANS capability related to their airframes, which were then combined and evolved into the FANS-1/A capability. FANS-1/A largely means that the airframe is capable of CPDLC and ADS-C applications. At the same time, ICAO developed a separate FANS definition that was based on the Aeronautical Telecommunication Network (ATN) set of protocols and standards – the ATN-B1 (Baseline 1). FANS 1/A and ATN-B1 are being combined in the form of ATN-B2[106], with initial operational capability having been already deployed and full operational capability expected by 2023.

Data links are enabled through the Data Link Initiation Capability (DLIC) which provides the necessary information to make data link communications possible between the ground and aircraft. DLIC works via a package of data links initiated on request by the pilot (Figure 7), made up of Automatic Dependent Surveillance (ADS – where an aircraft determines its position through a satellite), the Controller Pilot Data Link Communications (CPDLC) and the automatic provision of Data Link Flight Information Services (DFIS). The ground-to-air data link infrastructure is provided by L-Band Digital Aeronautical Communication System (LDACS)[107], with LDACS1 being the industry preferred format.

The CPDLC application provides the air-ground data communication service for ATC, enabling routine ATC clearances to be automated. These are already being used for non-safety-critical

Figure 7: Communications data link-based system



[105] https://www.skybrary.aero/index.php/Pilot-Controller_Communications_(OGHFA_BN)
[106] https://www.icao.int/APAC/Documents/edocs/GOLD_2Edition.pdf
[107] https://www.eurocontrol.int/system/l-band-digital-aeronautical-communication-system

instructions and communications. Using CPDLC, controllers can issue instructions (e.g. transfers, frequency changes) and clearances (e.g. speed, heading, direct-to, descend-to) using standardised data link messages. The use of a data link service such as CPDLC offers the potential to relieve some congestion and reduce workload, enabling more efficient trajectory management and thus scalability facilitating future growth. A 75% CPDLC equipage rate is estimated to generate an 11% reduction in ATC workload[108].

Satellite-based data link services can provide a significant contribution to the modernisation of communications systems delivering high-bandwidth, cost-effective communications to aircraft and airspace users that can be globally available and accessible. Satellites can also enable provision of broadband services for the cockpit using secure network connectivity to relieve pressure on congested VHF radio links, which are near capacity. Satellite-based data links such as an electronic flight bag (EFB) can be globally available to support pre-flight briefing to the pilot and on the ground through provision of flight documentation on electronic devices. The pre-flight briefing could take place directly on the EFB, receiving digital briefings from the ground and updated over a data link during the flight. Retrieval of the digital aeronautical data, including NOTAM and MET data, is enabled by means of SWIM and digital NOTAM. Satellite-based EFBs can improve pre-flight information sharing between all stakeholders (e.g. pilot, flight dispatchers and air traffic controllers) through the exchange of timely, synthesised and relevant digital aeronautical data.

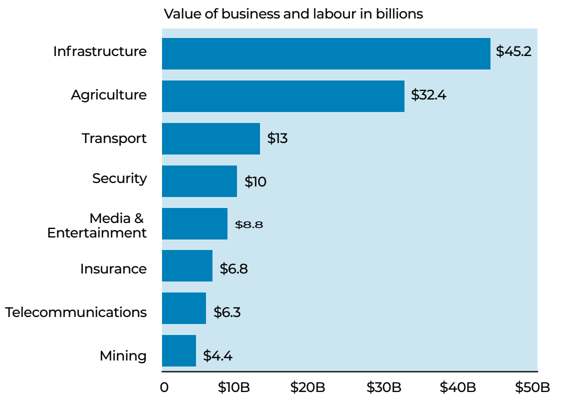
Satellite-based data link services will take advantage of network-based broadband to provide secure and high-bandwidth cockpit communications to exchange flight information and trajectory data with the ground. Aircraft communications are protected from cyber threats through using advanced technologies such as virtual desktop infrastructure (VDI), Layer 2 Tunneling Protocol (L2TP), IKEv2 (Internet Key Exchange version 2) and IPSec which refers to the internet protocol security suite, etc, which provide virtual private network (VPN) barrier between the ground and each aircraft, assuring mutual authentication and integrity of data exchange. Those technologies allow to protect the aircraft communications and securely connect flight management systems to the corresponding ground stations in highly reliable and trusted fashion.

ADDRESSING THE CHALLENGE OF FUTURE FLIGHT SYSTEMS

Automation will need to play a pivotal role in the scale up of the emerging global Unmanned Aerial Systems (UAS) future flight market. There has been an explosion of UAS application in recent years, accelerated by the COVID-19 situation. The drone services market size is expected to grow to $63.6 billion by 2025[109] and Goldman Sachs has forecasted the total drone market size to be worth $100 billion[110].

The potential for UAS, gathering data quickly from places that are difficult to access and creating an accurate 'golden record' in near real-time, is huge. Across sectors, from emergency services to energy, construction,

Figure 8: Predicted value of drones by industry



Source: Business Insider

[108] Source: Draft Rule for the Provision and Use of Data Link Services, Economic Appraisal, February 2007

[109] https://www.businessinsider.com/drone-industry-analysis-market-trends-growth-forecasts

[110] https://www.goldmansachs.com/insights/technology-driving-innovation/drones/

logistics, delivery and environmental surveillance, UAS have a growing role in meeting the fundamental modern needs for more efficient, safe and cost-effective services.

Many initiatives are underway to unlock the full potential of UAS applications, such as SESAR U-space[111] in Europe and in the USA with NASA's Advanced Air Mobility (AAM) and Urban Air Mobility (UAM) programmes and FAA's Unmanned Traffic Management (UTM)[112]. However, the level of automation support overall remains low. The deployment of advanced automation tools has been hampered by technical challenges such as the lack of a robust and ubiquitous global digital data link and limited use of data communications, limited information sharing and interoperability. Higher levels of automation will progressively enable

increased human (e.g. controller and pilot) productivity and hence efficient airspace capacity and integration. Furthermore, the operation of UAVs is limited globally by challenges associated with gaining regulatory approval for flight Beyond Visual Line of Sight (BVLOS) from the UAV's remote pilot. This challenge extends from unmanned aircraft flights having to follow the same 'see and avoid' regulatory principles with respect to collision avoidance as for manned aircraft. Regulators have tried to provide scope for development of UAS applications and development, setting out a Detect & Avoid (DAA) regulatory framework for operators of UAS. This outlines what is needed in terms of a DAA ecosystem to allow for BVLOS flights of drones in non-segregated airspace – how UAS must demonstrate mission protection capability through ensuring that collision avoidance can still be maintained, and satisfy the 'see and avoid' requirement of manned aviation. On the other hand, the proposed DAA guidelines lack target performance parameters.

Due to the technical challenges of UAVs and remote pilots being adequately informed of potential traffic threats, this requirement effectively prohibits BVLOS UAV flight in uncontrolled airspace, unless a specific UAV operational airspace is segregated from manned aviation traffic, often achieved by the use of a Temporary Danger Area (TDA) or other spatial discrimination arrangements. Recently in the UK, the CAA has updated its policy on using transponder mandatory zones as a means of maintaining safety where drones fly[113].

For quite some time, UAS regulation and safety assurance for BVLOS was caught up in a long-standing 'chicken-and-egg' situation. UAS technologies and collision detection systems have been readily available, but without clear regulatory performance targets for BVLOS flights they have not yet been deployed. However, a number of projects around the world are planning flight trials in the next couple of years to provide the significant body of evidence needed to verify the performance of these DAA technologies and thus gain approval for routine BVLOS flights, such as the SESAR U-space Very Large Demonstrators and NASA-FAA UTM Trials. The lack of generic, 'Type Approvals' by regulatory bodies means that if a technology is tested and validated in one environment and one specific region – by one airport, for example – this does not allow the technology to be deployed by another airport automatically. This has been the case for manned aviation systems, and is expected to continue to apply to the unmanned ecosystem. A robust methodology for defining acceptable targets for a DAA solution is essential to getting progress towards universally agreed standards. The situation is the

[111] https://mailchi.mp/caa/radio-transponder-mandatory-zones
[112] https://www.nasa.gov/utm
[113] https://mailchi.mp/caa/radio-transponder-mandatory-zones

same globally, where safety, performance, operational and regulatory requirements are very slowly being defined for UTM components. As part of the SESAR U-space and NASA-FAA UTM programmes, the definitions of expected UTM services have been provided, along with demonstrations to quantify target performance in various operational scenarios, but specific, quantified requirements are still being formulated. Evidence from both SESAR's U-space and NASA-FAA UTM trials have been fed into standardisation bodies such as European Organisation for Civil Aviation Equipment EUROCAE, European Union Aviation Safety Agency (EASA) and the Global UTM Association (GUTMA), to help the progress towards a framework of minimum operational performance standards and regulatory requirements. However, SESAR's latest report on demonstrator evidence has flagged that there is still the need for "advanced strategic/tactical conflict resolution, advanced DAA systems and a suitable communication infrastructure"[114].

Leveraging the experience from traditional ATM 4D enabling capability using ubiquitous Satcom (such as the SESAR Iris programme) can help address some of the automation challenges to provide a seamless and global connectivity solution that can integrate easily with UTM and support the growth of UAS. This capability has been demonstrated by Inmarsat and Altitude Angel Guardian UTM using flight trials, to deliver advanced flight tracking and management capability for UAVs and thus advanced

situational awareness. The so-called 'Pop-Up UTM'[115], can be deployed anywhere it is required to manage BVLOS UAV flights, without the need for ground-based communications infrastructure. By utilising Inmarsat's sector-leading global network of satellites and leveraging its substantial experience in ATM communications, Altitude Angel's Pop-Up UTM can be accessed rapidly and deployed worldwide. It will be developed initially to address the unmanned traffic management needs of blue light emergency services and first responders who need aerial surveillance rapidly with little notice, with a commercial, industry-focused product to follow soon after. Through this technology, emergency services will be able to remotely manage UAVs, increasing their range of safe operations in mixed airspace of manned and unmanned vehicles.

While the satellite industry has needed to play catch-up on integration with internet standards in the past, 5G is the opportunity for satellite service providers to collaborate more closely with mobile and fibre network operators, building their functionality and offering via multicasting and backhauling (connecting individual end users with core networks). That will mean the chance to realise the concept of ubiquitous coverage, connection anywhere in the world, anytime. 5G and satellite communications integration will enable coverage extension for 5G networks to places that terrestrial networks cannot reach and offloading by terrestrial networks via the use of satellite backhaul and traffic control.

The European Commission's SaT5G research project is setting out an example of how satellite communications can be integrated with 5G networks[116] – by defining the optimal solutions for satellite-based backhaul and traffic offloading (shifting traffic to complementary networks). The project has seen satellite integrated into 3GPP (Third Generation Partnership Project) 5G testbed networks and demonstrations of 5G use over live satellite links. As part of the SaT5G programme, funded by the European Space Agency (ESA), Asia's 5G

[114] https://www.sesarju.eu/node/3691
[115] https://www.inmarsat.com/en/news/latest-news/aviation/2021/altitude-angel-and-inmarsat-s-ground-breaking-pop-up-utm-wins-20.html
[116] https://www.sat5g-project.eu

revolution has developed an end-to-end 5G satellite-terrestrial integration to support aerospace integration[117].

While geostationary satellite services are used for aircraft operation networks, the advent of low earth orbit (LEO) satellite constellations bring significant capacity and reduced latency for airport backhaul services that create opportunities for increasing the reach and ubiquity of communications services to remote communities. A number of options exist for architecting the solutions, depending upon the nature of the deployment and the way in which services will be offered to customers.

Handover management, the transfer of voice or data between satellite and ground infrastructures, is likely to be a key airspace management challenge involved as a result of the growth of UAM concepts that offer both new transport options and ad-hoc mobile communication network base stations. Unlike fixed, terrestrial networks, devices moving through three-dimensional spaces, are inherently a difficult technical problem. Solutions to date have been based on the use of algorithms that evaluate packet routing, or simply based on received signal strength, basing handover decisions on the signal strength threshold system. The costs, accuracy and security of these handover methods will be enhanced by use of machine learning; however, a flexible management system for future generations of UAM networks is needed. For example, a handover system that can deal with the implementation of mmWave bands in 5G and 6G networks; the impact of the massive growth in numbers of connected devices on load balancing; that can provide a clustering algorithm to improve network performance.

Technological and regulatory evolutions, together with the advancements inherent to the UAS ecosystem, will pave the way for higher levels of collaborative and integrated airborne automation. This will be facilitated by transformative mechanisms to integrate and manage drone traffic and larger remotely piloted aircraft within conventional manned aviation airspace and operations. Groundbreaking traffic management solutions are currently being deployed that enable greater levels of autonomy and connectivity both in manned and unmanned aviation, bridging the safety and technological gaps for seamless integration. Major leaps from the status-quo are being implemented in all areas, with commercial passenger aircraft already moving towards single-pilot operations, acting as a stepping-stone to fully autonomous aircraft. The overall system will also seamlessly integrate flights above FL660 (66,000 feet), with entry and exit procedures through segregated or non-segregated airspace.

All these different frameworks will converge towards an integrated ATM where manned and unmanned aerial vehicles seamlessly and safely operate within the same airspace, leveraging common infrastructure and services. Crucially, the new collaborative environment will remove barriers to the growth of high-potential new market sectors with potentially satellite-based communications systems playing a key enabling role.

[117]https://www.ses.com/role-satellite-asias-5g-revolution

CONCLUSION

The management of post COVID-19 future air traffic growth, that will also likely include entirely new flight systems, while at the same time mitigating environmental impacts, will be dependent on transformation of the existing air traffic management system, including the airspace regulatory structures themselves, through the increased adoption of automation.

A priority focus on the whole industry roll out of Trajectory Based Operations that incorporate real-time satellite-supported 4D trajectory management, made possible through increasing the levels of collaboration and automation support, is seen as a critical step towards the future management of existing air traffic, so allowing more efficient traffic sequencing and routine deployment of so-called fuel efficient 'green descents' to airport terminal areas.

Part of the air space modernisation agenda is the deployment of more aircraft-to-aircraft and ground-to-aircraft data link services with higher levels of automation to accelerate the implementation of silent and safe electronic communications and so reduce the dependence on voice-based protocols. Satellites can enable provision of new broadband services for the cockpit using secure network connectivity to relieve pressure on congested VHF radio links.

Ground-based surveillance systems will have an important role to play in the future using a mix of new technologies and contracted service arrangements that frees itself from the constraints of existing legacy systems and creates new competitive market opportunities. Boundaries between different domains will disappear progressively as the infrastructure shifts to an integrated, cost-effective digital framework that includes an optimal mix of surveillance capabilities such as ADS-B, Wide Area Multilateration (WAM) and Mode S secondary radars, so making it possible to decommission all legacy systems.

Automation will need to play a pivotal role in the scale up of the emerging global future flight UAS market. Satellite systems will provide infrastructure support for future UAS and UAM by becoming a network of highly functional space-based digital processors with potential 5G network integration and handover management. Satellites are likely to replace functions that were once performed exclusively on the ground, such as onboard switching and onboard signal processing, becoming hubs of the global communications infrastructure. Global regulatory inertia, however, is seen as a significant barrier to market enablement. Programmes like the SESAR U-space and NASA-FAA UTM and UAM continue to work to bridge the gap between the lack of defined regulatory and safety requirements. However, SESAR's latest report on demonstrator evidence has flagged that there is still the need for "advanced strategic/tactical conflict resolution, advanced DAA systems and a suitable communication infrastructure".

6. THE FUTURE OF AIRPORT CONNECTIVITY

Airports could be considered as being at the centre of an aviation communications infrastructure, having the ability to handle vast flows of both old and new information to manage local aircraft movement, the direct needs of both passengers, plus their baggage, and of transiting cargo or freight.

Airport infrastructure stakeholders work together to ensure seamless operations and optimal efficiency, but the increasing complexity, demand and opportunities for sharing data across multiple domains make having a common communications platform and infrastructure essential. Cross-domain collaboration is made possible by unified, ready-to-use digital platforms for airports, able to translate and collate heterogeneous forms of communications: systems and processes that are digitally aware, interconnected, data-driven and simple to access. The interconnected nature of a future airport hub – handling sensitive, confidential and proprietary data – means data monitoring, security and access control will be a major priority.

For **passengers**, a fundamental requirement is a clear and easily navigable wayfinding system through airport complexes. This is particularly important for those travellers with some form of visual, physical or cognitive disability. Accessible travel and tourism is an important and growing market within the transport industry generally; according to the World Health Organisation, 15% of the world's population (more than one billion people) live with some form of disability[118]. In developed countries, ageing populations mean there are rapidly increasing numbers of people living with chronic conditions and disabilities, including unseen disabilities like dementia. Digital technologies can be used to augment typical airport design strategies and their environmental cues (e.g. signs, furniture, colour, lighting) and floor plan typology (e.g. reference points, process differentiation). Innovations in wayfinding solutions include Bluetooth technology to 'push' personalised directions and navigation-based messages to passengers or travelling companions in real-time on personal devices.

Baggage can have an 'identity' – just like that of passengers – that is tracked throughout a journey. Lufthansa introduced its RIMOWA electronic smart bag system in 2015[119]; the British Airways' TAG was offered from 2019. Increasingly, passengers will have more choices – as a standard offering – for how their bags are transported: the option for bags to picked up separately from their home, office or hotel and transported to the airport; or passengers could choose to leave their bags with dedicated, secure drop-off points located in shops or transport hubs. Using a smart device, passengers are now able to track the status and location of their baggage in real-time across the journey, receiving push notifications as reassurance that bags are being received and processed, and immediate access to tracking information should a bag be misplaced. The tracking apps are generally available through the airlines that operate them (such as the case with Delta, United Airlines and American Airlines)[120]. Alternatively, air regulation compliant universal trackers are now available in cases where the airline cannot provide them[121].

[118]https://www.who.int/news-room/fact-sheets/detail/disability-and-health
[119]https://www.lufthansa.com/de/en/smart-bags
[120]https://www.airfarewatchdog.com/blog/29305779/how-to-track-your-luggage-from-the-plane/
[121]https://www.gego.io/

Processing of baggage through security will also be automated, with risk-based security measures triggering additional screening procedures where necessary. A digital image record of a passenger's baggage is automatically added to their travel profile, allowing customs, security and other border controls to clear the bag for arrival, or refer the passenger for a secondary screening. At the airport, autonomous vehicles and specifically designed robots transfer bags from ground transport connection points, automatically check customs and security details, and transfer them to the correct flight.

Connectivity, technology and data sharing is also set to revolutionise the **cargo** journey of the future. Enhanced network visibility will allow stakeholders from across the supply chain to obtain real-time information on capacity, service levels and capabilities of different providers on specific trade lands. It will also be the platform for fully integrated scheduling, leading to optimal pick-up and drop-off of cargo and freight at origin and destination.

Cargo will be able to be monitored and tracked throughout the journey, with context specific information – such as the status of commodities and environmental conditions – monitored and transmitted in real-time. Based on this information and status of the shipment, predictive analytics can be used to make operational decisions regarding onward transport and warehousing.

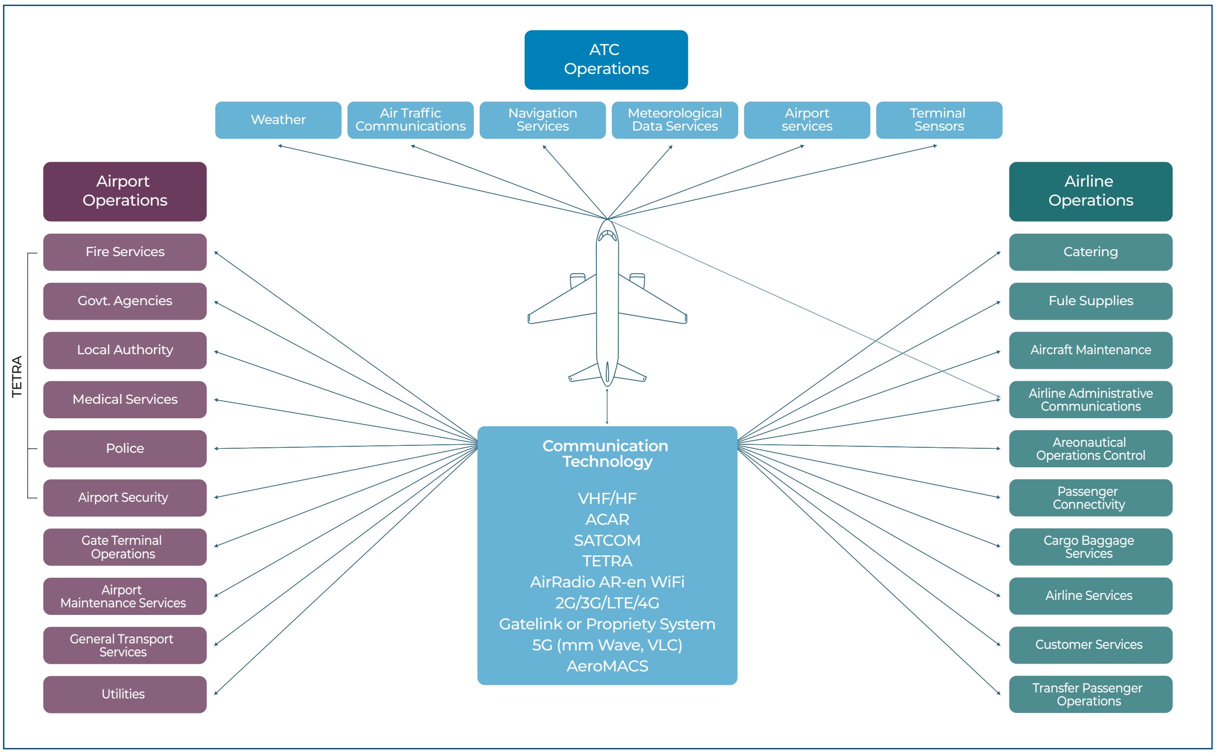
Local **aircraft movement management** is clearly mission critical for airport operation, whether the aircraft is on final approach or take off or taxiing to the stand. Issues related to data latency, reliability and scalability are aggravated by increased network sizes and interactions between stakeholders and the necessity for heterogeneous networks, devices and applications to work seamlessly together. Any future network roadmap will need to identify potential operational concerns with emerging new communications technologies for aviation systems to increase the awareness that can improve the airport operation flow of aircraft, goods and people. Early identification of these concerns will enable the design of more reliable systems for entering the market. Future communications networks will increase the reliability of communication from different sources and types of operation: to help with predicting capacity demand; enhance the passenger travel experience; improve operational process efficiency and staff productivity; as well as increase safety and security. The process of identifying heterogeneity in itself, the different technologies and vulnerabilities in current airport systems, will directly improve the resilience and integrity of aviation security. It will also help with highlighting potential operational concerns involved with emerging aviation technologies, enabling weaknesses to be 'designed out' prior to their entering the market. Features of the roll-out of many past aviation technologies have been delays and slow progress, with a need for legacy systems to remain in service due to operational concerns not accounted for in the design and development phases.

AIRPORT AND AIR TRAFFIC MANAGEMENT

A transformation in the capacity and reliability of airport and air traffic connectivity, particularly using wireless technologies, over the last decade has provided a platform for enhanced airport operations and new airline digital services (Figure 9). However, reducing system complexity remains the biggest challenge.

There are now multiple wireless sensor systems generating vast streams of operational data to the ground control centre; wireless applications replacing traditional paper-based services to deal with airline administration and sending passenger details to the aircraft crew; data to improve surface operations, low visibility operations, collaborative ATM, performance-based navigation, improved weather and navigation information. At the same time, different airlines have different route structures, airport facilities, IT organisations and fleet preparation. The rapid growth of piecemeal technologies, however, has led to data noise with many different parts of operations able to speak to each other alongside a mix of new,

Figure 9: Interoperability between airline, airport and air traffic management operations



legacy and obsolete technologies. This leads to challenges of latency (slower speeds), reliability and scalability of communications, especially for airport networks based on mission-critical and time-sensitive scenarios. For example:

- High bandwidth data connection is required that can enable transfer of larger data sets during an aircraft's gate turn, taxiing or while at a maintenance facility.
- Upload of time-sensitive inflight entertainment data and cabin logbook entries, Flight Operations Quality Assurances (FOQA) data, engine performance data, and cabin logbook entries that enable rapid response to aircraft problems and tuning of flight performance parameters for maximum flight efficiency.

Getting universally agreed and adopted communications standards has challenged the sector. In 2016, the European Organisation for the Safety of Air Navigation (Eurocontrol), SESAR and FAA finally jointly agreed on a single solution – recommending the Aeronautical Mobile Airport Communications System (AeroMACS)[122]: the new-generation airport data link to help airlines, airport authorities and Air Navigation Service Providers (ANSPs) cope with increased volumes of data exchange at busy airport surfaces. Due to its frequency spectrum and level of security, AeroMACS has become the only globally standardised aviation technology designed to support the safety and regularity of flight, ATC, AOC and airport authority communications simultaneously. Operating in the aeronautical C-band (5 GHz) for short-range and high-data rate communications AeroMACS is based on the commercial 4G technology using the WiMAX standard (IEEE 802.16) offering a broadband IP data link with worldwide interoperability, enabling integration of critical communications for air traffic services, airline operational communication and airport authority communications[123]. AeroMACS is currently deployed at Lisbon airport, with other implementations planned for Europe and the US, Japan, China and Brazil.

[122] https://www.eurocontrol.int/system/aeronautical-mobile-airport-communications-system-Data Link
[123] https://www.eurocontrol.int/system/aeronautical-mobile-airport-communications-system-Data Link

THE ROLE OF 5G

The future of the connected airport will not necessarily be solely dependent on the newest frontier technologies such as high-band 5G and LEO satellite constellations. Much of it will be defined by the expansion and evolution of existing connectivity technologies, like low to mid-band 5G, and various other long- and short-range solutions. Connected architecture in airports also includes cloud and edge computing that can be accessed with cheaper – and more efficient – 'thin' (lower performance) devices. The advantage of 5G lies in the provision of very high data rates, extremely low latency and an increase in base station capacity. Ericsson research suggests the ultra-reliable low-latency communication approach of 5G to be the most applicable to the digital aviation ecosystem[124]. Increasing the range of connections and users will inevitably increase the data flow and capacity requirement, while 'transport turnaround time' will stay the same or reduce. That means finding methods to increase the capacity of airport systems without increasing the burden placed upon time and frequency.

5G and satellite integration: historically, satellite capacity has been expensive. The significant costs of satellite procurement, launch and operation have limited the potential of the market to develop. But satellite communications are also integral to delivering the vision of a reliable, high-performance environment for digital connectivity anywhere in the world. Adapting satellites to work seamlessly with 5G cellular and terrestrial networks will give service providers the flexibility to make choices and use combinations of satellite, terrestrial and mobile networks to ensure a consistent and reliable service for users globally. For this to happen, satellite comms must become a standard radio interface within the multi-radio network architecture of 5G, allowing intelligent 5G networks to engage satellites seamlessly and quickly. Significantly, Inmarsat has announced its Orchestra solution that will use its existing satellite services (L- and Ka-band) with terrestrial 5G and a network of LEO satellites within a layered 'dynamic mesh network'[125].

DATA MANAGEMENT AND SECURITY

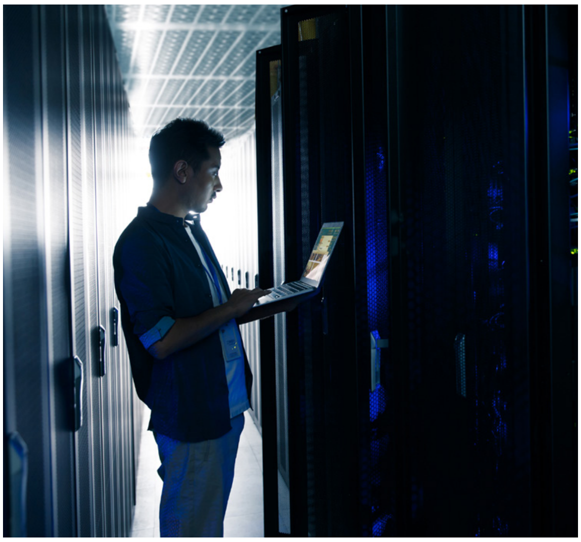
Flexible and evolving cybersecurity infrastructures need to be factored into the design of any system, including airport data services from the earliest stages of the process, due to the variety of security concerns related to application environments and communications technologies used.

The EASA has estimated that aviation systems are subject to 1,000 cyber-attacks every month[126]. Existing aviation security technologies and processes have been developed to manage physical attacks, primarily involving the physical segregation of people and material through physical access controls, screening and monitoring. However, as the range of types and frequency of intersections between physical and cyber domains in airports increases, more and more domains will become dependent on the networked communication links transporting data from sensors to the 'actuators' (which might be human or automated/mechanical).

Data security and integrity are the central and imperative attributes for data management. Unbound wireless communication – like that between aircraft and the gate prior and post-flight – is inherently 'open', with no means of providing physical protection. The nature of the airport digital ecosystem means multitudes of data focused and stored in a single set of databases, file systems and storage infrastructure. This kind of concentration is more of a sitting target for cyber-attack than individual data packets crossing a network. Data 'at rest' is more open to hacking because it is subject to logical structuring and tagged in a meaningful manner that can then be predicted and made accessible. Any 'sitting' data in airports must be encrypted in line with industry standards (such as the Advanced Encryption Standard – AES 256).

[124] https://www.aviationpros.com/airports/airport-technology/article/21154285/airport-5g-moves-from-concept-to-reality
[125] https://www.inmarsat.com/en/about/technology/orchestra.html
[126] https://www.easa.europa.eu/domains/cyber-security/overview

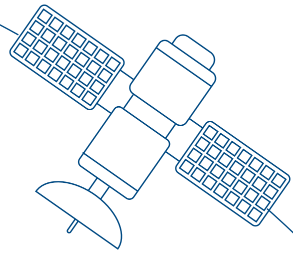
In a wired network an attacker must navigate several layers of defence, such as firewalls and operating system levels; in a wireless system the intruder can attack any node. There are two broad types of attacks a network might face: structured and non-structured. Structured attacks can be defined as expert hackers who will have developed their own, often sophisticated attack strategies, such as the 'zero-day attack': where the hacker finds a vulnerability in software code before the developers have and exploits the flaw or error. Unstructured attacks are carried out by amateurs, often in the form of 'password crackers' (algorithms used to predict passwords) or malicious 'shell scripts' (re-writing command-line code to evade security rules). Attackers can also be either local, via someone who has authorised access to a network via an account or physical access; or external from those without access.



Current cybersecurity methods used within airports can be limited and lack the all-important need for flexibility to meet the growth in the use of IoT connectivity. Intrusion Detection Systems (IDS) can be signature-based, where a network intrusion and packet logging software looks for patterns in network traffic that suggest malicious activity and instructions based on a community-driven set of rules. Despite the effectiveness of IDS in systems handling high volumes of data, they also have the potential to create a data backlog. Due to the rule-driven nature of detection, signature-based detection is also ineffective against zero-day attacks. Anomaly-based IDS use machine learning to compare models of trustworthy and untrustworthy activity and are able to pick up on previously unknown forms of attack. Anomaly-driven approaches can lead to higher rates of false positives, categorising any kind of original activity by system users as a threat.

Flexible cybersecurity approaches are crucial for allowing evolution that puts detection and security responses ahead of the work of cyber-criminals. Systems need to be able to evolve beyond their original scope and to meet changing needs of the variety of airports and their services at local, regional and international levels.

Maintaining data 'integrity' means airports need to have an explicit overview and understanding of what data is being collected, who is collecting the data, how it is being used and who has access. The value of passenger and flight data is crucial for the aviation business; there is also a significant issue around who 'owns' certain data. For instance, passenger application providers or airlines or ISPs. Sharp attention needs to be paid to the rights of individuals to decline to have their personal information collected, as well as to the assurance of data accuracy and consistency over its entire lifecycle. As a basic rule, data security and integrity need to be monitored and controlled through using access and authentication mechanisms w the potential to become significant drivers of future communication technology design because of several high-volume data synchronisation services, including, but not limited to, data delivery to the cockpit, ground operations and services, unified customer database, aircraft data operations and inflight entertainment data.



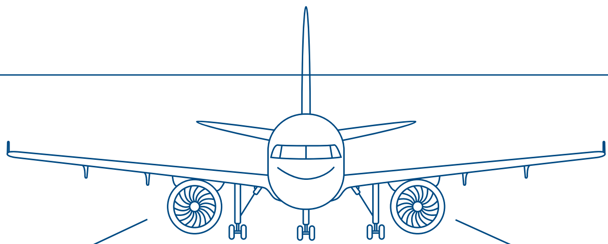
CONCLUSION

Airports are at the centre of an aviation communications infrastructure handling large quantities of time sensitive data to manage local aircraft movement plus directly benefiting the efficient movement of both passengers plus their baggage and transiting cargo.

Digital infrastructures are being developed to create more efficient wayfinding for passengers through the airport, more intelligent and responsive baggage tracking and real-time updates on the condition and progress of cargo in transit.

The management of aircraft movements are core to an airport's operation. Multiple ground-based wireless sensor systems (such as VHF data links) generating operational data to the airport's ground control centre provide improved surface operations, low visibility operations, collaborative ATM, performance-based navigation and improved weather and navigation information. The rapid growth of piecemeal technologies, however, has led to data noise caused by a mix of new, legacy and obsolete technologies, so creating latency, reliability, and scalability concerns.

Airports of the future will increasingly rely on forms of ultra-reliable, low-latency 5G provision. The advantage of 5G lies in the provision of very high data rates, extremely low latency and an increase in base station capacity. Satellite enabled provision, although having an initial infrastructure cost challenge, when linked with cellular and terrestrial networks will give service providers the flexibility to make choices and use combinations of satellite, terrestrial and mobile networks to ensure a consistent and reliable service for users globally.



7. ARTIFICIAL INTELLIGENCE AND DIGITAL TRUST TECHNOLOGIES: UNDERPINNING THE PASSENGER EXPERIENCE

Artificial Intelligence (AI) and digital trust technologies have enormous potential for being applied across multiple aviation applications across all the four aviation sectors described previously in this report so impacting on passenger experience in all forms. To provide full justification of the potential impact of AI and digital trust technologies within aviation would require extending this paper significantly. The following therefore represents a simple introduction that will be expanded upon at a later date.

Deep neural networks, built on big data, cheaper cloud computing, computer-based vision, the IoT and graphics processors, have all narrowed the gap between the imaginable and real-world applications. AI can provide intelligent advice on aircraft management issues and make informed decisions under pressure (when there is the need to make a diversion for example), with camera-based traffic detection, or helping crew to anticipate and prevent critical situations. AI should generally aim at improving the accuracy of any application from sensor calibration, fuel tank checks, icing detection[127].

AI will also be the foundation for creating future solutions to complex challenges, such as the demand for urban air mobility in the world's congested cities. Unmanned aircraft will be reliant on systems able to make complex decisions to ensure safe flight and landing; for example, managing the separation between air vehicles based on reduced distances compared with conventional air traffic management practices. This is where AI makes the difference in delivering full autonomy, the powerful algorithms to deal with huge amounts of data generated by embedded sensors and by machine-to-machine communications. There are still no benchmark cases of large-scale applications in the aviation industry - and there are major question marks over trust in AI and its ability to make ethical decisions. The planning, construction, maintenance, and optimisation processes of AI and communications networks will need to be gradually combined. Within the context of aviation connectivity there are many emerging high value use cases a few of which are illustrated below;

Airport stand optimisation
AI is already being used to increase the capacity of airports through dynamic stand reallocation systems. For example, one such system has been reported to be capable of reducing the time required to reallocate stands for in excess of 1000 flights from hours to one minute resulting in a 7.4% increase in daily flight capacity.[128] Similar AI driven systems are used to manage allocations of check-in counters, boarding gates and baggage carousels so contributing to the overall airport efficiency and passenger experience.

Digital Content Buffering
AI can be used to find trends in passengers' information needs based on time and location and buffer the data which is expected to be requested by passengers in flight, such as the news. When the aircraft is on the ground (prior to flight) and has access to fast and low-cost broadband internet, the data can be downloaded and stored, subsequently delivering the same content "offline" during the flight to passengers through the aircraft's onboard Wi-Fi, thereby reducing the load on the aircraft's live satellite broadband connection.

[127] https://www.easa.europa.eu/sites/default/files/dfu/EASA-AI-Roadmap-v1.0.pdf
[128] https://www.internationalairportreview.com/article/162211/creating-passenger-experience-through-big-data-model/

Voice Recognition
AI can be used for voice recognition and transforming the voice communication between ATC and pilots into text in order to assist pilots to understand ATC dialogue better and avoid errors. Such systems are purposely trained for aviation specific vocabulary as used by pilots and ATCs and can provide textual feeds of multiple audio communications channels directly to onboard avionic systems or offboard handheld devices.[129]

Unmanned Traffic Management
In order to guarantee a highly available UTM framework that is scalable, of low overhead and energy consumption, and capable of real-time processing of shared data, advanced technologies such as ML can be used for operation planning, trajectory prediction and optimisation, situational awareness (weather awareness, terrain awareness, obstacle awareness), and failure detection and recovery. The use of ML algorithms for Urban Air Mobility vehicle operation planning can be vital, especially for cases where collecting or getting the operation trajectory information is challenging or not applicable, such as operations in a hostile environment. It can also help reduce the computational complexity in the search of feasible flight paths.

Complimentary to AI and ML digital trust technologies such as distributed ledger and identity management have the potential to play a key role across the door-to-door journey to the benefit of the connected passenger experience. Conceptually, blockchain and distributed ledgers describe a type of distributed database that leverages crowd computing and related infrastructure. The technology has been applied in a wide range of applications across a variety of sectors, with a number of potential applications for aviation. An example is the opportunity posed for improving and streamlining the process of earning, spending and accounting for frequent flyer points as introduced by the Singapore Airlines Group. By digitalising these programmes, frequent flyer points can become more pervasive across different sales channels and across different airlines within an alliance[130]. Blockchain technologies can also be used for tracking the status and location of assets like baggage or cargo, allowing visibility of these across the journey. For passengers, this could provide valuable reassurance that bags have accompanied them on their journey, but also help to quickly locate bags if they are lost for any reason.

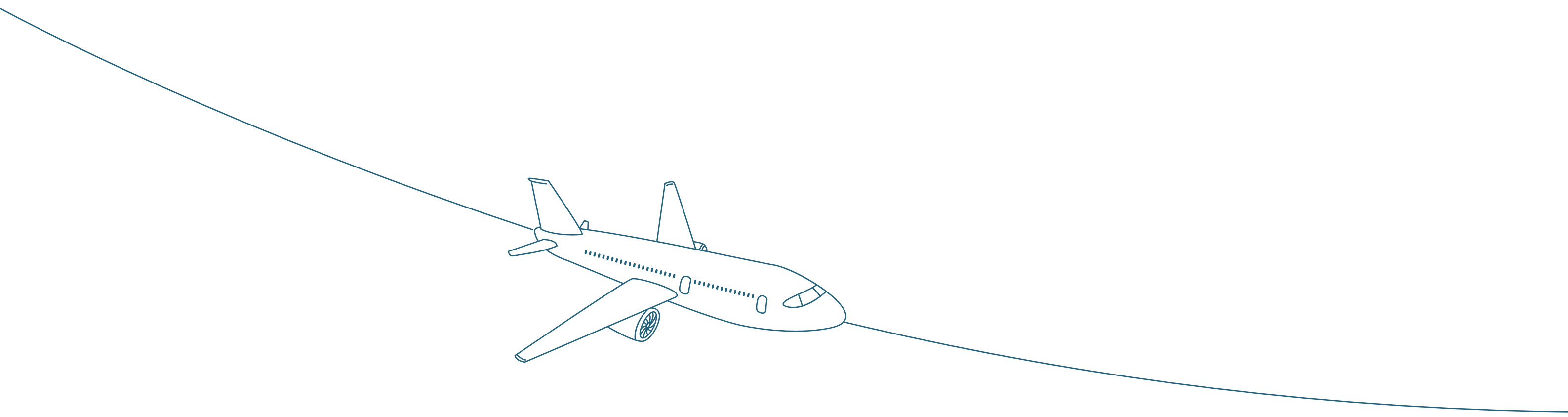
The technology can also be used in the context of identity management. This can be especially powerful when linked with passenger verification technologies like biometric recognition systems, including face, iris, or fingerprint technologies. An example includes IATA's ONE ID initiative[131], which seeks to streamline the passenger journey by introducing a document-free process based on a simple, single identity management system, underpinned by advanced and biometric

[129] https://appareo.com/aviation/aviation-speech-recognition-system/
[130] https://www.singaporeair.com/en_UK/sg/media-centre/press-release/article/?q=en_UK/2018/January-March/ne0518-180205
[131] https://www.iata.org/en/programs/passenger/one-id/

recognition systems. The aim is for ONE ID to benefit both the passenger, who will no longer need to juggle multiple physical documents, but also benefit the operator, who will be able to easily locate a passenger at any stage of the air travel. For example, this could be especially useful for locating passengers who have checked-in for a flight but failed to board for some reason.

Similarly, facial recognition identity systems, such as the Thales FRP technology and other biometric systems , also have the added benefit of reducing the number of physical 'touchpoints' along the passenger journey, given that these systems will typically rely on identification using cameras and other sensors. During a period when airlines need to re-build passenger confidence and enhance the air travel experience as a whole, digital systems like these can reduce the amount of time spent on manual ID checks, reducing queuing times and even raise the potential for the completion of all immigration processes while on board. For airline operations there is improvement in passenger flow and the potential for staffing efficiencies at border and security checkpoints as inspection processes and protocols become increasingly automated.

Advances in identity management are also the foundation of risk-based, differentiated screening of passengers, baggage and cargo. These kinds of digital systems apply screening measures and protocols in a tailored way, according to the risk category of the passenger, or situation, and allow for resources to be targeted more effectively. Risk-based screening and security means heightened and sharpened attention in the right places: critical to helping reduce risks from terrorism, criminal activities such as human trafficking, the smuggling of drugs and narcotics and illegal trafficking of wildlife.



8. THE CRANFIELD-INMARSAT DIGITAL AVIATION ROADMAP

Using the information presented throughout this paper, the authors have attempted to summarise the development in digital aviation technologies and systems in the form of a roadmap. As was mentioned in Chapter 2 the technology change cycle times vary significantly across the sector with, for example, significant changes being enabled within 6 to 12 months within the airline operations sector to 5 to 10 years for the airport operations. The roadmap needs to reflect these large variations but at the same time present a simple summary and will do so by considering just three broad timelines:

- **Within 5 years** – Technologies and systems that are at advanced stages of development and in some cases are being piloted by organisations ahead of market adoption.
- **5 to 10 years** – Technologies and systems that are under early development and have the potential to be trialled in some sectors.
- **Beyond 10 years** – Technology concepts that are under consideration for product or service offering development.

Clearly the boundaries between the various timelines are fluid and it is quite possible that some technologies might be introduced earlier or later depending on market and regulatory forces, nonetheless the roadmap provides an informed overview as to how and where the sector is expecting digital technologies to impact on its future.

WITHIN 5 YEARS

Health and Wellbeing

Enhanced onboard sanitation using UV-C cleaning of cabin surfaces, and widespread adoption of digital health passports.

Travel Personalisation

Real-time travel information and personalised wayfinding using computer vision techniques, supported by tailored commercial offerings to enhance journey experience.

Passenger Travel Security

Adoption of early biometric monitoring for increased airport security.

ATS Management

Increased ATM operational capacity through reduced dependence on ATC voice commands (via satcom enabled data link services), next-generation multi-channel programmable software-defined VHF radio and remote provision of Air Traffic Services (ATS).

Uncrewed Traffic Management

Initial Beyond Visual Line of Sight (BVLOS) operational frameworks with operator enabled configuration and control through virtualisation and satellite communication elements via 5G network integration.

Onboard Passenger Digital Experience

5G streaming of digital media content to personal devices, offering new e-commerce and entertainment opportunities to the airlines and operators.

Airline Asset Management

Application of big data principles, predictive analytics and machine learning for enhanced airline asset management through fleet operational optimisation and human resource planning.

Aircraft Data Management

Improved flight and aircraft data management through the deployment of Electronic Flight Bag services, inflight transmission of aircraft maintenance data and aircraft predictive maintenance scheduling.

Airspace Information Harmonisation

Initial framework design and services from ICAO's System Wide Information Management (SWIM) initiative within the Global Air Navigation Plan (GANP).

Trajectory-Based Operations (TBO) and Green Descents

Initial 4D deployment and Single European Sky Imaging through initial technology and multilink interface designs that include satellite communications and L-Band Digital Aeronautical Communication systems (LDACS).

Airport Multi Stakeholder Interoperability

Enhanced multi-vendor airport terminal and hub interoperability through providing seamless system of system (SoS) interface characterised by technical specifications including architecture, protocol stack and radio access levels.

5 TO 10 YEARS

Health and Wellbeing

Smart cabin environments sensing passenger temperature, anxiety and hydration levels, enabling enhanced comfort management by crew and resulting in increased customer satisfaction and crew work experience.

Passenger Travel Security

Walk-through security screening using AI enhanced 3D scanning approaches with material discrimination, high rates of detection and low levels of false alarms, providing both increased security and uninterrupted passenger airport movement.

Passenger Travel Security

Adoption of identity recognition technology in combination with behaviour analysis to identify abnormal passenger behaviour within airport terminals, creating a safer environment.

Future Flight Airspace Integration

eVTOL Aircraft airspace integration can be via digital-data exchanges, such as Controller Pilot Data Link Communications (CPDLC) or System Wide Information Exchange (SWIM) protocols.

Communications Infrastructures

New communication infrastructures are expected to be deployed, using Digital Terrestrial Transmission (DTT) and Satellite Hybrid Wireless Mesh Networks to improve backhaul networks and virtual network operators.

Inflight Data Capacity

Implementation of Artificial Intelligence to provide inflight bandwidth selection optimisation for greater data capacity and resilience.

Inflight Data Capacity

Implementation of Artificial Intelligence to provide inflight bandwidth selection optimisation for greater data capacity and resilience.

Airspace Information Harmonisation

Full System Wide Information Management (SWIM) implementation, enhancing global airspace information exchange and airspace utilisation.

Trajectory Flight Optimisation (TBO)

Advanced deployment with full integration of flight information and synchronised view of flight data by all actors involved, providing enhanced airspace capacity and reduced fuel burn.

Aircraft Data Management

Advanced aircraft digital data capture approaching 100 billion gigabytes per year, enabling widespread sector adoption of predictive maintenance scheduling that will reduce aircraft downtime.

Uncrewed Traffic Management

Regulatory framework for advanced BVLOS operations enabling commercial cargo, B2B drone operations and initial passenger air taxis services.

Airspace Surveillance

Global satellite-based digital data links enabling Automatic Dependent Surveillance Contract (ADS-C), Extended Projected Profile (EPP) downlinks airspace surveillance performance.

Aircraft Data Management

Whole aircraft digital twin representation fully enabled through aircraft sensor data and launch of prototype self-aware and self-reasoning aircraft having “consciousness”.

BEYOND 10 YEARS

Data Communication Integration

Deployment of intelligent IoT networks (e.g. mesh) and virtual network operators, providing air-to-ground and air-to-air connectivity integration.

Communications Infrastructures

Application of 6G core network-based AI, cloud edge computing and use of quantum encoding to manage data privacy and authentication.

Airspace Management

Virtual centres associated with sector-independent ATS enabling dynamic, optimised and shared management of airspace.

Aircraft Data Management

In service "conscious" aircraft and emergence of "zero maintenance" platforms.

Aircraft Maintenance

Remote inflight or ground based aircraft servicing and emergence of pilot led maintenance support using VR/AR seamless communication between maintenance engineers and aircraft self-awareness (consciousness).

Airspace Management

Service-based approach to surveillance and communications infrastructure.

Uncrewed Traffic Management

Regulatory framework for routine BVLOS operations in all environments (including urban) enabling B2B and B2C drone and UAM taxi services.

Trajectory Based Operations (TBO)

Full 4D deployment enabling ATS to adopt a supervisory service.

Aircraft Maintenance

Prototype "lights out" automated MRO hangars that are activated on demand.

CONTACT

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