The Policy and Regulatory Challenges Arising from New Aviation Technologies

Northpoint Aviation
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November 2025

INDEPENDENT TRANSPORT COMMISSION

Published by the Independent Transport Commission and the CAA

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Acknowledgments:

The ITC would like to record its gratitude to the Civil Aviation Authority (CAA) and Strategic Aviation Special Interest Group (SASIG) which have part-sponsored this study, as well as to our corporate members, a list of whom can be found on the main ITC website (**www.theitc.org.uk**). The support of these organisations has made this research project possible.

This report was authored by Chris Cain and Northpoint Aviation, with the assistance of the ITC and CAA Steering Group members including: Dr Stephen Hickey, James Bell, Terry Hill CBE, Professor Peter Jones OBE and Dr Matthew Niblett. We are grateful to all those organisations that were involved in the consultation exercises, and also to those who have kindly reviewed drafts of the report, including: Professor Romano Pagliari, Dan Simpson, Graeme Elliot, David Skinner, Basil O'Fee and Keith Artus.

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Foreword

Aviation is essential to modern societies – for families, businesses, education, tourism, cargo and communications. It is also a major industry, in which the UK is an important global player, employing thousands in often highly skilled jobs.

But today it faces major challenges. This report highlights three:

A. **Environmental sustainability:** the urgent – but extremely difficult – need to cut emissions;

B. **Congestion and capacity:** the need for more efficient use of capacity in the air and on the ground;

C. **Advanced Air Modalities:** the new opportunities offered by drones and other emerging aviation technologies.

Aviation has met past challenges by harnessing new and improved technologies. This report highlights the huge range of potentially transformational technologies becoming available to meet these we face today.

Although these technologies are at different levels of maturity, and sustained research and development (R&D) remains essential, the report concludes that the prime focus now needs to be on the practical tasks of implementation, for example:

- scaling up new fuel sources so they become commercially viable and physically available;
- implementing airspace modernisation and next-generation infrastructure;
- tackling the practicalities of deploying Advanced Air Mobility more widely and safely;
- developing space launch capability and infrastructure.

The report stresses that this cannot be done by industry alone but needs collaboration with investors, academics, regulators and Government. It needs to involve international partners and local and regional authorities. And it must engage with 'adjacent' industries, for example those tackling wider decarbonisation, developing new materials and deploying the latest advances in digital technology.

The report concludes that success requires strong, collaborative, 'mission-based' leadership. It calls on Government to refresh and reinvigorate its recent progress, through a clear policy and leadership framework, overseen by a pro-active Aviation Technology Board. The prize could be a modernised industry, serving customers efficiently and sustainably and making a major contribution to UK economic growth.

Dr Stephen Hickey
Chair, ITC Aviation Research Committee

The Policy and Regulatory Challenges Arising from New Aviation Technologies

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Executive Summary

1. Introduction

1. Aviation is currently undergoing a period of significant change, shaped by emerging technologies that have the potential to transform both how we fly and how we experience air travel. Some of these technologies are already at an advanced stage, while others are in early development or awaiting a catalyst that will enable them to be scaled up to a level that is commercially viable. These innovations, ranging from Unmanned Aerial Vehicles (UAVs) to new forms of propulsion, have emerged to meet a number of needs and challenges. Particularly critical is the need to reduce the carbon impact of powered flight and set the industry on a more sustainable trajectory. While much attention has been given to the technical aspects of these innovations, there has been far less investigation of the policy and regulatory impacts new technologies will have. In our view it is essential that policy makers and regulators understand these impacts if they are to adapt successfully to such innovations and reduce the risk of negative impacts.

2. To explore this important topic, an independent consortium comprising the Independent Transport Commission (ITC), the Civil Aviation Authority (CAA) and Strategic Aviation Special Interest Group (SASIG) has commissioned this research study from Northpoint Aviation. The brief asked the researchers to examine the policy challenges presented by emergent aviation technologies with a focus on four core issues. First, to explain the strategic challenges facing the industry that are driving the current wave of innovation. Second, to identify which technologies will become commercially viable or be rolled out at scale before 2050. Third, to examine the likely impacts of these technologies on the aviation industry, services and future operating models, and finally to explore the major policy and regulatory issues arising from widespread adoption of these technologies, as well as identify the policy and regulatory responses necessary to address these issues.

Methodology

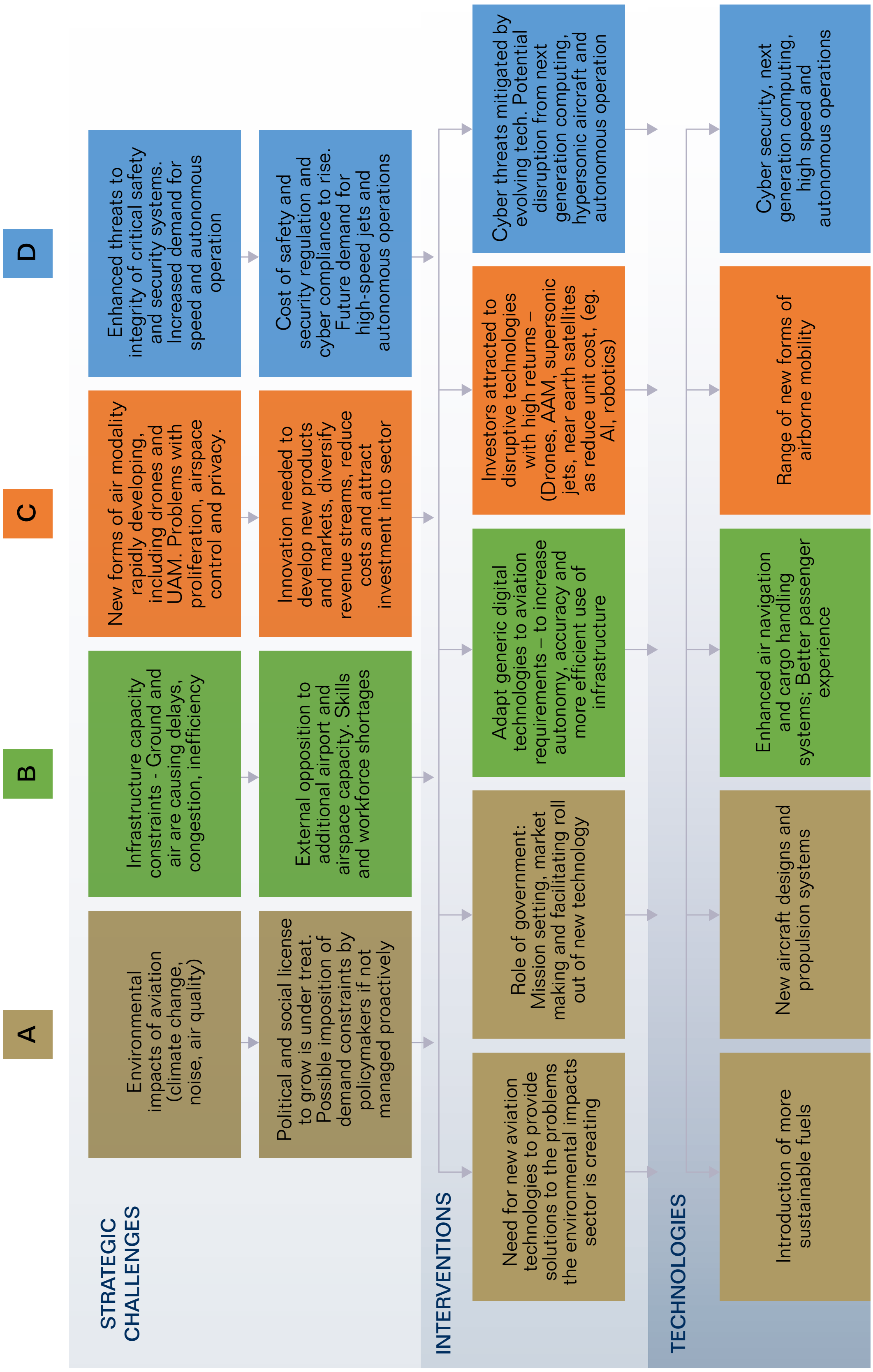
3. The research team chose to explore these questions through a range of techniques. These included a thorough literature review to understand emerging technologies and their prospects, a questionnaire survey of, and five roundtables with, key stakeholders and experts. This consultation provided fresh and valuable insights into the current policy and regulatory landscape, and the likely impacts of new technologies. Finally, desktop research and evaluation has taken place with the project Steering Group and selected expert reviewers to provide feedback and ensure accuracy.

Core Challenges

4. Over the past few decades, globalisation and the increased social demand for air travel have driven largely incremental innovation in the sector. But over the past decade, the industry has come to face potentially paradigm-shifting challenges that require revolutionary, rather than evolutionary technologies to solve. An analysis of these challenges identified three core strategic issues that are driving innovation. First, the urgent need **to make aviation environmentally sustainable**, particularly in terms of reducing carbon emissions from powered flight. As other economic sectors decarbonise faster, aviation is comprising a greater proportion of global carbon emissions, and pressure is increasing on the industry in the context of ambitious net-zero carbon targets set by the UK Government. Second, in the UK there is a major challenge around **congestion and capacity constraints** associated with growing demand for flying. Infrastructure capacity constraints at major airports and outdated airspace management systems are leading to increased disruptions, delays and inefficiencies in aviation services for both passengers and freight. There is an economic imperative to solve this problem urgently. The third core challenge is **the potential of new air modalities** to reshape air services and the use of airspace. The growth in particular of unmanned aerial vehicles (UAVs) promises to provide new solutions to current problems by enhancing urban, regional and rural mobility for purposes including healthcare, deliveries, and infrastructure monitoring. Such modalities are also being developed to support the nascent UK space sector, given the growing economic need to maintain and handle satellites. The researchers also identified other strategic challenges to the aviation sector, including cyber disruption, skills deficits and economic crises, but these were considered less technical issues to address in terms of policy and regulation.

5. For each of the strategic challenges identified, the researchers examined new and emerging technological innovations that had the potential to make significant impacts. These innovations and their impacts are summarised in Figure 1 on the next page. In the case of **making aviation environmentally sustainable (A)**, the most immediate focus is the development of sustainable aviation fuels (SAF), which could be used in the existing fleet. The challenge here is less technology per se and more about how to incentivise, invest and scale up to the levels needed across the industry. New propulsion systems are also being developed, and work is ongoing to retrofit small aircraft, with relatively limited range, with electric or hybrid hydrogen-electric power trains. In the longer term more radical technologies are likely to be needed, including hydrogen jet engines. Several initiatives have been launched, but scaling up to large-scale commercial use is still expected to be decades away. A third key area of innovation to improve sustainability arises from new aircraft designs, using improved materials and adjusting the aircraft mainframe and wings. Revised aircraft design can improve their aerodynamic performance and therefore their fuel efficiency. Nonetheless, since such innovations require fleet replacement, these are unlikely to see widespread commercial use in the next two decades.

Figure 1: Aviation's Strategic Challenges and potential Technological solutions



Source: Northpoint Aviation

6. In terms of addressing **congestion and capacity constraints (B)**, the foremost set of new technologies under development relate to airspace management. Important tools being introduced include Global Navigation Satellite Systems (GNSS), precision area navigation (P-RNAV) and universal conspicuity which all should improve flight delays and free up Air Traffic Control capacity. Many of the new management tools are reliant on a range of generic digital technologies, including robotics, 5G and Artificial Intelligence. The next generation of satellite navigation systems will also provide ultra-precise positioning for aircraft and enhance flight safety. These various navigation enhancements will also contribute to better sustainability by enabling improved routing and more efficient use of airspace. Investment in digital technology will also enable better passenger travel experiences at the airport, driven by innovations such as biometrics to improve passenger identification, and blockchain ledgers to improve baggage checking and freight/cargo management. These could increase the handling capacity at airports and reduce mistakes and delays.

7. The **impacts of new aviation modalities (C)** could be transformational. Advanced Air Mobilities (AAM) in the form of drones and small fixed wing aircraft, are already widespread, and other innovations include electric and hybrid-electric aircraft capable of short take-off and landing (STOL) and vertical take-off and landing (VTOL). These developments could radically widen the utility of aerial vehicles for multiple purposes, especially as the infrastructure required for take-off and landing and ground handling will be much more compact. For example, it should improve the prospects for Regional Air Mobility (RAM) to facilitate middle-distance trips of 75-225km between regional locations. The scope for Urban Air Mobility (UAM) operations could also be transformed, although this faces challenges related to limitations of space and safety in highly populated areas. To address this challenge technological advances are also being made in lower airspace management to improve the safety and security of AAM operations, while sites are being identified for a first generation of drone and vertiports. The UK Government is helping the industry to pioneer this kind of innovation through initiatives such as the Project Skyway corridor. Another form of new modality relates to delivery platforms for the positioning and maintenance of low-earth orbit satellite operations. The Government is keen to ensure the UK remains globally competitive in satellite technology and is supporting the development of spaceports at several locations across the UK.

Prospects for Aviation Emergent Technologies

8. Although the breadth and scale of technological innovation in the aviation sector is remarkable, it also has the potential to generate wide-ranging impacts and new policy issues. After assessing the technologies outlined above, the researchers evaluated the prospects for each and their likely significance. Those with good prospects are likely to have a material impact on the industry in the next decade, including Sustainable Aviation Fuels, smaller electric-powered aircraft for shorter flights and the use of new materials to produce more efficient aircraft and engine designs. Most airspace and passenger facing technologies were also assessed as likely to make strong progress over the next decade, as enhanced digital technologies are deployed and adopted at scale. In terms of new aviation modalities, a proliferation of drone and

E-VTOL aircraft is anticipated over the next 15 years, whilst satellite technology and different forms of high-altitude platforms are also deemed to be industries where the UK will seek to play a leading role in the future.

9. With a wide range of new technologies likely to become mainstream over the next couple of decades, the prospective impacts will be significant, and various hurdles will need to be overcome if they are going to become commercially viable. Sustainable Aviation Fuels will require policy measures and financial support to scale-up quickly, as well as designing and locating infrastructure capacity to take advantage of alternative feedstocks and sources of green energy to facilitate production at scale. Electric-powered aircraft need to be developed with sufficient capacity and range to make them commercially viable. New airspace management systems need to be developed to take-advantage of rapid enhancements in digital technologies, although the key challenge here will be to implement new systems safely. Passenger facing technologies are at a more advanced stage of development and will be introduced incrementally as business and operational demands justify them. In terms of new air modalities, the prospect of a proliferation of drones in highly populated areas poses important challenges for regulation by local and national bodies. There is also significant public scepticism about the widespread roll-out of AAM beyond current public service and survey roles, with concerns focussing on privacy, safety and noise.

Policy and Regulatory Considerations

10. Policy makers in both national and local Government have a crucial role to play both in enabling the scaling up of new technologies, and in ensuring these are implemented and managed safely and in a socially acceptable way. At the same time, the UK Government and its industry regulators and agencies need to act in accordance with the legal obligations arising from the hierarchy of institutions that govern aviation at an international, national and local level. To its credit, the UK Government has already set in motion a range of initiatives to support the strategic co-ordination of prospective technological advances in aviation. These initiatives include the Jet Zero Strategy to achieve a low-carbon aviation future, the recent Future of Flight Challenge to support technological innovation, including drones, and wider initiatives by the UK research and innovation agencies to develop battery technology, digital systems and innovate aerospace design. Regulation is currently provided through bodies including the Civil Aviation Authority (CAA), which regulates aviation and spaceflight activity, and works with air traffic service providers like NATS, while the UK Space Agency (UKSA) provides strategy and policy direction for the space sector.

11. Different levels of technological maturity require different approaches by policy makers and regulators. Emerging technologies often require proactive intervention to finance and support research and development. Incremental technologies such as biometrics and automation are easier to finance privately and bring to scale, but where a technology involves a step-change in performance, functionality or a major disruption to the existing market such as SAF or e-VTOL, then public sector support to help share the risks of development becomes more important. The precautionary principle behind regulation, and the importance of safety in all aviation matters, point towards the need for careful oversight of new technology until the longer-term risks and benefits are fully understood, whilst also designing 'smart' approaches like the CAA's 'sandbox' initiative so that progress in the certification and roll out of innovation is not stalled. Policy makers and regulators also need to be aware of the social acceptability of emergent technologies in order to avoid generating major opposition.

12. A number of policy gaps and shortcomings have been identified that need to be addressed if the UK is to continue to be a world leader in aviation innovation. These include the absence of a Strategic Framework for Aviation Technology which could co-ordinate innovation in the sector. This will require collaboration both across and beyond the aviation sector, in particular with the wider energy sector as well as finance, logistics and a range of general-use technologies. A wide range of policy interventions will be needed, such as a clear long-term policy framework; market-making initiatives; targeted direct or indirect financial support; fiscal incentives; and, in some areas, directions or mandates (such as the longstanding controls on night-time noise, and the more recent mandate requiring the use of SAF). Such a strategy needs to take a long-term view of objectives over a period of 20-30 years at a minimum. The lack of sector champions to advocate for new technologies and drive forward a programme is also a concern. There currently are skills shortages in a number of crucial areas, including aviation IT, which need to be addressed, as well as supporting training in crucial future areas such as AAM operations and standards development. The lack of a comprehensive communications strategy is a policy gap that should be filled to ensure that the public and target audiences remain supportive of innovation goals.

Conclusions and Recommendations

13. Aviation forms a vital component of the infrastructure that links the modern world together, facilitating face to face global interactions in a way that neither the internet, nor other modes of transport, can achieve quite so holistically or expeditiously. At the same time, the industry faces many challenges, and this report has shown how new technologies have a prime role to play in meeting these. In terms of **making aviation environmentally sustainable**, there is growing consensus that SAF has the greatest near-term potential, with hydrogen in the longer-term. But electricity, using batteries and hybrid fuel-cells, can also play an important role. For the objective of **reducing congestion and capacity constraints**, the need to use IT, AI and other data-driven technologies to transform the management of airspace (and, increasingly, airports themselves) will improve both operational efficiency and the experience of consumers. Finally, in terms of **the potential of new aviation modalities**, a striking feature of the decade has been the rapid growth of new technologies, notably drones but increasingly other forms of aircraft, opening-up the prospects of entirely new airborne services and business models.

14. This report shows that there is now widespread recognition of what we believe are the core challenges facing the sector. In particular, the need for sustainability; better customer service and operational efficiency through better management of airspace and ground services; and the opening up of the opportunities for new services and new business opportunities offered by new forms of flight. The current UK Government and its predecessor have recognised these challenges and opportunities and has worked hard, in collaboration with the industry, the aviation regulator (CAA) and others to drive the process forward. At the same time, this review has confirmed that the path ahead remains extremely difficult. Our overall conclusion, therefore, is to welcome the real progress made by the industry, regulators and Government over the last few years; but to recognise that we are still at the very early stages of actually implementing the transformational changes required. Moving from (in broad terms) the 'R&D' stage to 'industrialisation at scale' is a massive, difficult but urgent challenge – and a key enabler of the Government's wider Missions for both Growth and Climate Change.

15. Our recommendations include several actions for the Government to take forward in collaboration with the industry. First, **the Government should adopt a comprehensive strategy for aviation transformation** through the deployment of the new technological opportunities, with a 20-30+ year horizon. Second, it should establish **an overarching leadership and governance framework**, to oversee the aviation transformation strategy and provide accountability and transparency. Third, within this – and building on the current arrangements – the Government should **embed a range of focussed programmes** to drive forward progress in key areas of innovation and transformation. Finally, it is essential to **place a strong focus on tackling the challenges of commercialisation, industrialisation and implementation at scale**. Wider actions that will encourage success in this field include developing a strong culture of collaboration, as well as creating **transparent engagement and communications with the wider public**, in order to give clarity of policy direction, goals and progress. With these measures in place, it should be possible to retain public support for the UK's aviation sector, while also meeting the many strategic challenges ahead. We have also offered a series of other more granular recommendations where we believe there are interventions that can be addressed quickly, cost effectively or result in enhanced planning and better delivery.

1. Background

1.0 Introduction

1.0.0 UK aerospace and air transport sectors, taken together, make up a large and important industry. Its significance extends well beyond the direct economic outputs it creates in terms of jobs, GDP and added value. It also generates a wide range of catalytic benefits such as connectivity to overseas markets, facilitation of trade flows, investment and tourism. When these broader economic considerations are taken into account, alongside aviation's social, educational and cultural roles and its strong international and regulatory dimensions, its status as a high value industry and important form of transport requiring significant government engagement quickly become clear.

1.0.1 For a new government which puts growth front and centre of its policy agenda for the remainder of the decade, whilst also taking its local and international environmental responsibilities seriously, the importance of finding a policy approach that will allow aviation to remain on a growth trajectory, whilst at the same time reducing its environmental footprint, is a crucial but challenging policy dilemma that needs to be resolved. Is the wave of new aviation technologies that are currently coming forward potentially the key that unlocks it?

1.0.2 The innovation of which the industry is capable, is visible in the periodic technological transformations that the industry has experienced over its 120-year history. The majority of those affecting civilian aviation have been concentrated into the post-war period, in response to the rapid underlying growth of the sector and followed a 20-year cyclical pattern driven by major **strategic challenges** that were specific to their time. And as we start the second quartile of the new millennium, a new set of such challenges have duly arrived for the industry to face. As before, they are leading to a new wave of innovation.

1.0.3 The impact of the current wave of change is, however, somewhat different, as it is expected to combine **evolutionary**, and in some cases **revolutionary** technologies, as part of a wide range of emergent technologies, that either:

- address directly the key challenges facing the industry – most notably the need to decarbonise, tackle increasing congestion and deal more effectively with various external shocks or threats; or
- respond to opportunities for significant disruption of established markets and processes facilitated by efficiency gains, improvements to the passenger experience and new forms of mobility.

1.0.4 Decarbonising the sector by achieving Carbon Net Zero operations by 2050, and ultimately even Zero Carbon Flight, is recognised within the industry as being imperative for its long-term future. Failure to meet the targets for reduced climate change emissions, set for aviation at a national and multi-lateral level, could give rise to increased external opposition to the sector and threaten the license to grow that the industry has hitherto enjoyed. But if investment in carbon reduction technologies succeeds, then the new aircraft designs, propulsion systems, fuels and air navigation enhancements it gives rise to, will create opportunities for even greater demand and improved resilience on which the success of most airline and airport businesses depend.

1.0.5 However, achieving this transition will involve overcoming huge obstacles, both technical and financial. First, there are stringent regulatory frameworks that the new technologies need to satisfy, then a cost base that established industry business models can afford needs to be achieved. Following which there is the expensive and long-term process of replacing existing aircraft designs with new ones, presenting transformative wing and mainframe configurations and innovative propulsion systems dependent on new power sources such as electricity and hydrogen. All these new technologies require significant investment if they are to come to market and then effective operational and commercial management if they are not to turn into unmanageable risks.

1.0.6 Strategic objective setting, effective regulation and risk sharing are therefore seen as crucial in addressing these challenges, with international experience highlighting clearly the importance of governmental engagement and leadership at all levels from national to local, and a constructive approach from other important stakeholders if private operators and investors are to make the essential long term funding commitments. Social acceptance will play a pivotal role in determining the scope and pace of these developments.

1.0.7 The aim of this report, therefore, is to offer an overview of this evolving aviation landscape, to highlight anticipated challenges and opportunities, and underscore the importance of proactive government engagement, regulatory alignment, and stakeholder collaboration, if the full potential of new emerging aviation technologies is to be realised.

1.1 The ITC Report Series

1.1.0 This report is one of a long-standing series dedicated to offering targeted and objective research on key issues facing transportation and land use policy commissioned by the Independent Transport Commission (ITC). The ITC's reports, which are often co-sponsored with partner organisations – in this case the Civil Aviation Authority and the Strategic Aviation Special Interest Group of the LGA (SASIG) – present insightful, forward thinking but, most importantly, independent findings that aim to facilitate discussions within the sector and ultimately inform and challenge policy makers.

1.1.1 The ITC has produced a dedicated stream of work relating to UK aviation policy and strategy within its broader research programme. This has yielded several impactful reports, each delving into important challenges confronting the UK aviation industry. Most recently, two such reports focused firstly on how UK air connectivity could be enhanced, and latterly, on how aviation can be made more sustainable environmentally in the medium to longer term[1, 2]. They address the future trajectory of UK air connectivity, especially within the context of post-Brexit Britain, and its endeavours to establish new global trading relationships. They also underscore the pressing need to address critical issues such as noise mitigation and reduction of carbon emissions, highlighting the imperative of rolling out as quickly as possible sustainable practices across the aviation sector.

1.1.2 In keeping with this mission of providing essential guides, offering valuable insights and making recommendations into the challenges and opportunities shaping the aviation policy landscape in the UK, this new report seeks to draw together in one readily accessible place, the discourse and extensive literature about a wide range of strategic challenges now facing the aviation sector in the UK. Its focus is on the timely wave of innovation that has initiated the development cycle of several important new technologies, just at the time when the significance of these strategic challenges to the sector has begun to emerge.

Focus of the Current Report

1.1.3 Following feedback on the earlier reports and engagement with stakeholders, it became clear that aviation today faces major **strategic challenges** and, simultaneously, a remarkable range of emerging technologies. The ITC therefore decided to commission a review of these technologies, their potential contributions to meeting the challenges, and the policy issues likely to arise.

1 Rebecca Driver, The Strategic Challenges Facing UK Aviation: Assessing the Future of Air Connectivity (Independent Transport Commission, 2017).

2 Peter Hind, The Sustainability of UK Aviation: Trends in the Mitigation of Noise and Emissions (Independent Transport Commission, March 2016).

3 Driver and Hind reports cited above.

1.1.4 The terms of reference for the report are set out in full in Appendix A (available separately online); a summary is provided here. In short, the ITC required that we should examine the policy implications of the emergent aviation technologies with a particular focus on four core issues:

i. What are the strategic challenges and opportunities facing the aviation industry which are driving the current wave of innovation? Is the development cycle associated with the new aviation technologies likely to be completed before 2050 and what disruptive effects might they give rise to and what challenges would they bring for policy makers?

ii. How might public attitudes respond to the widespread adoption of these technologies, and what impacts will the public risk appetite have on the development of regulation and policy responses?

iii. What are the likely impacts of these technologies on the nature of the aviation industry? Will they provide opportunities for new or different kinds of services and service providers, and what will this mean for future operating and business models? Will there be any potential conflicts or trade-offs between a) the emerging technology and existing operations and b) the growth of the technology and social and environmental impacts.

iv. What policy and regulatory issues will be raised by widespread adoption of these technologies and what conditions would be necessary for them to become commercially viable and be rolled out on a significant scale by 2050? What kind of policy response should the government and regulators seek to provide to achieve this?

Objectives of the Report

1.1.5 In response this report seeks:

- To bring a wide-angle lens to a broad range of relevant technologies; however, it should be noted that it is designed to offer an overview not a detailed analysis of the individual technologies.
- To horizon scan the policy implications of the key challenges and opportunities the aviation industry will face in the period to 2050 and offer insights and recommendations that help the industry, regulators and government plan for their potential impact.

In doing so it will review available evidence on the public's thoughts about new aviation technologies, their potential value, impacts and overall acceptability. The report is not aimed at technical specialists involved in each of the technologies we discuss, it is more for a non-specialist, wider industry and policy-maker audience. It asks questions of policymakers, regulators and decision-makers across the policy and regulatory spectrum, whilst highlighting key issues and possible responses for those seeking to influence them within investor, NGO and other stakeholder communities.

1.1.6 In addition to the strategic challenges which form the focus of this report, there are others of key importance. Perhaps the most immediately significant of these is the **impact of aircraft noise** on human health, particularly for communities living near major airports. Although there does not appear to be a single 'solution' to this problem, some of the technologies discussed do have the potential to contribute to the mitigation of this and other crucial challenges facing the industry.

1.2 The Role of Aviation in the UK[4]

1.2.0 To put the challenges the aviation sector is facing in perspective we first need to understand the industry's role and significance to UK plc[5]. This merits a much fuller treatment than is possible in this report. However, to provide background and context we have flagged some of the key considerations as follows:

- **Global Connectivity:** Aviation enables rapid and efficient travel between distant locations, connecting people, businesses, and cultures across the globe. It facilitates international trade, diplomacy, tourism, and cultural exchange. Air transport moves around 4.5 billion passengers annually and 61 million tonnes of freight[6].
- **Economic Growth and Job Creation:** The aviation industry contributes significantly to economic growth by supporting various sectors, including tourism, hospitality, manufacturing, and logistics. It creates direct and indirect employment opportunities, providing jobs to millions of people worldwide. The Air Transport Action Group estimates that the industry generates a total of 87.7 million jobs globally.
- **Trade and Commerce:** Aviation plays a crucial role in facilitating global trade. It provides for the timely and efficient transportation of goods and products, enabling businesses to access international markets and consumers, securely and in good condition (e.g. perishables such as pharmaceuticals and foodstuffs). Air transport is necessary for transporting high value, time-sensitive goods: 35% of world trade by value and less than 1% by volume.
- **Tourism and Travel Industry:** Aviation is a key driver of the tourism and travel industry. It brings tourists to various destinations, boosting local economies and supporting the hospitality sector: 58% of international tourists travel to their destination by air[7].
- **Time Savings and Productivity:** Air travel significantly reduces travel times for long distances compared to other transportation modes. This time-saving benefit is essential for business travellers and enables people to reach their destinations more quickly; while air freight is frequently a pre-requisite for just-in-time manufacturing, R&D, and advanced producer services requiring a global reach.

4 See also ACI, IATA, ICAO and AOA publications which discuss this issue with a wider scope and in more detail.

5 Here we mean not just commercial air transport (passenger and cargo) and General Aviation, but also the leasing and financing, and aerospace sectors – the latter covering the manufacturing (parts and assembly), servicing, storage and ultimately recycling of aircraft, ground equipment and physical infrastructure.

6 Air Transport Action Group (ATAG) – Aviation Beyond Borders (2020).

7 ATAG Ibid.

- **Emergency and Humanitarian Response:** Aviation plays a critical role in emergency and humanitarian response. It is critical in providing operating platforms that offer blue light services: speed, specialised capabilities, and efficacy of outcome. It also enables the rapid transportation of medical supplies, aid, and relief personnel to disaster-stricken areas.
- **Research and Development:** The aviation industry drives technological advances, particularly in materials science, engineering, and aerospace technology. These innovations often have broader applications beyond aviation. The importance of the industry in the UK in terms of generating well paid jobs was explored in an earlier ITC report[8] which covered much of this ground. Aerospace also provides high skilled, well-paid work in every region and country of the UK, directly employing over 100,000 people[9].
- **Innovation and Competition:** The aviation sector fosters competition among airlines, aircraft manufacturers, and service providers. This drives innovation, leading to improved services, more efficient aircraft, and enhanced safety standards.
- **Cultural Exchange:** Aviation promotes cultural exchange and understanding by facilitating international travel and interactions between people from different backgrounds and regions.
- **National Security and Defence:** Aviation plays a crucial role in national security and defence by providing rapid transport capabilities for military personnel and equipment.
- **Remote Area Accessibility:** Aviation is essential for accessing remote and isolated areas that are difficult to reach by other means of transportation. It helps support communities in these regions with essential supplies and lifeline services.
- **Scientific Research and Exploration:** Aviation supports scientific research and exploration, including aerial surveys, environmental monitoring, and space exploration missions.
- As ATAG puts it **Aviation's global economic impact** is estimated at $3.5 trillion (including direct, indirect, induced and tourism catalytic effects). If the aviation industry were a country, it would rank 17th in the world in terms of GDP.

1.2.1 There is little question, therefore, that aviation makes a major contribution to the modern world, offering numerous benefits that enhance global connectivity, economic prosperity, and societal well-being. In short, aviation is the true physical World Wide Web[10]. This makes the challenges it faces and the need to address them effectively that much more important.

8 Rebecca Driver, The Strategic Challenges Facing UK Aviation: Assessing the Future of Air Connectivity (Independent Transport Commission, 2017).

9 (BEIS) analysis of ONS employment data for Flight to the Future Report.

10 Oxford Economics: Aviation the Real World Wide Web, for ATAG (2009).

1.3 Examining the Strategic Challenges Facing Aviation

1.3.0 The **strategic challenges** the aviation sector currently faces are multi-faceted, ranging from structural capacity shortages leading to operational inefficiencies and reliability issues, as the limits of existing technologies are reached and are less able to cope effectively with externally generated disruptions and impacts. While some challenges are too small or commercial in nature to demand direct government intervention and are being tackled by the industry through the adoption of incremental enhancements to existing technologies, others are much more significant and require more radical approaches including co-ordinated sectoral and political engagement at both national and international levels[11,12]. These include:

- **Growing pressure to decarbonise to meet net zero targets**, within the timescale required by law. Until recently, there was no coherent plan as to how this might be achieved without significant constraints being placed upon future growth and potentially even existing levels of flying. While considerable efforts have been made since the turn of the decade to address this shortcoming, huge challenges and uncertainties remain – increasingly around the financial and logistical challenges of implementation at scale rather than technology itself.
- **Diseconomies of scale associated with congestion**, that prior to Covid led frequently to delays or service disruption for passengers, have begun to reappear as the industry recovers post-pandemic Although not unique to the UK, they are synonymous with many congested airport and airspace systems in North America and Europe, but the UK industry's concentration around London has led to increased delays and disruptions on the ground and also in the air.

How to realise the **opportunities opening up by new forms of aviation** such as drones, vertical-lift or short-field lift electric craft, new platforms for near earth satellites and others. The UK needs to maintain a competitive position in both the development and utilisation of these emerging technologies, which have the potential to radically change both the industry itself and business models of the future.

11 This distinction between the existential threats facing the industry and the associated strategic challenges they give rise to and more routine industry problems that may require fixing but do not raise fundamental question marks about the future size and shape of the industry is made throughout the report.

12 Similar differentiation has also been made between the policy interventions/measures under consideration or still needed and the initiatives/frameworks that have been put in place or which have yet to be developed.

1.3.1 Finally, there is the emergence of lower profile, but also valuable, **incremental technologies that are impacting the sector**, not least passenger experience enhancements (e.g. biometrics, mobile-based virtual reality), freight digitization and automated handling, with the introduction of robotics in some areas also in prospect. The application of generic new digital technologies such as AI, machine learning and quantum computing to the optimisation of airport operations and air navigation systems is also in its early stages; and it seems certain that enhanced cyber protection systems will become critical in tackling the challenges associated with digital disruption and failure.

1.3.2 The rapid emergence of so many new technologies – or at least their prototypes – over the same time-period, creates a broad agenda for policy makers seeking to stay abreast of developments and determine which are likely to offer the greatest short and longer-term contributions to meeting the major challenges facing the sector. Failure to address these challenges will not only undermine public, corporate and investor trust in the sector but also make transparent to a wider audience the existential risk to aviation's social, and therefore, political licence to grow. There are positive indications that the Government has grasped the importance of addressing these challenges head-on and being pro-active in bringing forward policies that will do so.

1.4 Scope of the Research

1.4.0 This is the context against which the search began within the industry for both short and long-term technological solutions to the growing range of challenges it faces (see Chapters 2 and 3).

Focus of the Analysis

1.4.1 To make the research that underpins this report manageable in terms of its scope, emphasis was placed on:

- major step-change or disruptor technologies, as opposed to incremental improvements[13];
- challenges facing civilian/terrestrial aviation (e.g. including near-space satellites and positioning systems, but excluding military and space technologies);
- short- to medium-term time horizons that embrace the next decades, up to around 2050;
- technologies where the UK is competitive or influential in defining policy and regulation.

13 While recognizing the significance of continuous incremental improvements, the study highlights the imperative for aviation to deliver advances in performance and environmental sustainability to garner social support, reduce environmental impacts, and drive market growth.

1.4.2 It is important to recognise that technology – or technology alone – cannot meet all the challenges facing aviation. For example, in situations where delays, congestion and restrictions on growth are ultimately caused by limited runway or terminal capacity, better airspace management and operational procedures – enabled by improved technology – can help. But ultimately additional physical capacity on the ground may be essential, unless the Government and wider society is willing to accept capacity-led limits on the demand for flight. Conversely, if growth in aviation is judged to remain important on economic, social or other grounds, then the need to tackle the problems of sustainability through better technology becomes an even higher priority.

1.4.3 In conclusion, the research aims to provide a helpful overview of emerging aviation technologies within a carefully delineated scope, aiming to inform responsive policy making and facilitate the realization of transformative advances in the aviation sector.

Collaborative Working

1.4.4 The scope of the study was carefully delineated in collaboration between the project funders: namely the ITC, the CAA and SASIG. Together, they formed a Project Steering Group, which reviewed interim findings, identified priorities, and refined the report's structure.

1.4.5 The **Civil Aviation Authority (CAA)** participated in this project as a member of the advisory Steering Group and contributed financially to support the research and drafting process. The CAA's involvement focused on ensuring factual accuracy and appropriate representation of regulatory frameworks. While the CAA did not author or endorse the report's conclusions or recommendations, its contribution helped ensure that references to safety, regulation, and emerging technologies were technically sound and appropriately framed.

1.4.6 Throughout the research and drafting process of this report, the authors have actively engaged with key stakeholders, including its principal sponsors:

- **The Independent Transport Commission (ITC):** Supported by a panel of academic and industry advisors, the ITC has provided invaluable insights and guidance throughout the research.
- **Civil Aviation Authority (CAA):** As the UK's specialist aviation regulator, the CAA provides regulatory and policy expertise in safety, security, consumer protection, airspace management, and environmental considerations, as well as strategic insight on regulatory matters affecting emerging technologies.
- **SASIG – Strategic Aviation Special Interest Group of the LGA:** SASIG represents local authorities with airport shareholdings or operational airfields in their boundaries. Their interest in new aviation technologies stems from their impact on local communities, connectivity, and economic development.

1.5 Phase 1: Baseline Research

1.5.0 The initial research phase underpinning this report was conducted via four distinct modules:

Desktop Research (Literature Review)

1.5.1 First, a thorough literature review was conducted, reviewing existing scholarly works, industry reports, and policy documents. This desktop research provided a foundational understanding of the landscape surrounding emerging aviation technologies and has been updated throughout the preparation of the report into early 2025 in order that, in a fast-moving area of innovation, it remained as up to date as possible.

Questionnaire Survey

1.5.2 Second, a questionnaire survey was distributed to a diverse range of stakeholders with core interests in the emerging technologies within the aviation sector covered in the report. These included policymakers, regulators, industry experts, and other relevant stakeholders. The survey aimed to gather insights, perspectives, and feedback on key challenges facing the sector, potential technology solutions that could be of value to the sector and the kind of policy needed to help realise them.

Roundtable Discussions

1.5.3 Third, roundtable discussions were convened, bringing together groups representing diverse perspectives on the issues under consideration. These discussions facilitated in-depth conversations, knowledge exchange, and collaborative problem-solving among stakeholders. The roundtables offered valuable insights into the complexities and nuances of the policy and regulatory landscape, both emerging and that would be needed, to realise the potential of promising new aviation technologies.

Contribution of the Steering Group

1.5.4 Fourth and finally, the research for, and drafting of, this report has also been significantly improved by the invaluable contributions, observations, and suggestions of the ITC's Project Steering Group. Their expertise and guidance played a pivotal role in setting the direction of the research, helping to improve the structure of the report, clarify priorities, advise on the balance between chapters and clarify priorities. The authors express their gratitude for the invaluable input received from the Steering Group. The conclusions and recommendations themselves remain those of the authors.

1.5.5 For those interested, further details on the methodology and these component elements can be found at Appendix B of this report (available separately online).

1.6 Phase 2 – Assimilating the Research Findings

1.6.0 The second phase aimed to integrate expert insights and stakeholder input with a thorough examination of literature, trends, and analysis. This work involved extensive consultations with industry experts, academia, and other external stakeholders, and separately staged presentations in the development of the report to a Project Steering Group encompassing the commissioning organisations.

1.7 Phase 3: Reporting and Publication

Report Structure

1.7.0 The remainder of the report is organised into chapters, with appendices and other supporting material providing further detail, where helpful. The second chapter highlights the key challenges facing UK aviation, while the third chapter examines the new aviation technologies that are emerging. In the fourth chapter, we assess which of these technologies will have the greatest impact and over which timescales, as well as the emerging policy issues arising. The fifth chapter examines how Government should approach its role in terms of driving policy and regulation, while the sixth examines the policy and regulatory challenges of the new technologies and highlights where attention is particularly required. This is followed in Chapter 7 by a set of Conclusions and Recommendations for policy makers and the aviation regulator.

1.7.1 In a field as broad and complex and subject to such rapid change as this one, this report has been a long time in its gestation. However, this has allowed us to draw on a wide range of sources and to take account of the advice and views of many contributors, from those who completed one of our stakeholder questionnaires and participated in the roundtables during the initial stages; to the vital contribution of the Steering Group overseeing the research and from those who more recently have acted as peer reviewers. All have assisted immeasurably in helping us to produce this report as the conclusion to our programme of work.

1.7.2 To complement this report, a number of Appendices have been compiled which are available separately online at the ITC's website via the following link: www.theitc.org.uk/our-research/research-reports-2. A Glossary is also provided at the end of the report for those unfamiliar with the wide range of aviation industry acronyms.

Publication

1.7.3 The report and its appendices are publicly available electronically on the ITC's website: www.theitc.org

Hard copies of the report have also been made available to those who contributed to the research and to the key organisations and decision-makers at whom it is targeted.

2. Highlighting the Key Challenges Facing Aviation

2.0 An Industry Where Technology Shapes Development

2.0.0 Commercial passenger aviation has grown hugely over the last 80 years, transforming a small, expensive, luxury good into a relatively affordable form of mass market transport which, although at its most mature in the Western hemisphere, is also showing rapid growth in Asia and the Middle East. In addition, air cargo plays a key role in international trade, with 40% of UK visible goods moved by air and e-commerce taking an ever-larger share of UK retail markets. All projections show that these trends are likely to continue, particularly as living standards rise across more of the globe.

2.0.1 Historically, it has typically been operational or commercial drivers, such as the size of aircraft available and the speed and distance that they can fly, that have shaped the industry. These changes have often generated step-changes in operations, based on upgrades in the hardware of flight:

- Propeller to turboprop (1950s) to jet propulsion (1960s) and hi-bypass engines (1970s/80s).
- Short haul narrowbody to long haul widebody aircraft (1970s).
- Advances in avionics and navigation systems (1980s and 90s).
- Four engines to large twins for long haul aircraft (1990s and 2000s).
- Ultra long rage variants for narrowbodies (2010s).

2.0.2 But more recently, since the beginning of the 21st Century, cost and efficiency have become increasingly dominant factors, reflecting globalisation, growing competition and the increased worldwide demand for travel. The technological innovation to enable this has often been incremental in nature, or focused on operations, software and environmental improvements. For example:

- To service long haul destinations and keep growing at ever more congested hubs – more direct flights using longer sectors and Extended Range Twin Operations Approvals (ETOPs), while slot shortages at busy airports have led to new procedures to manage sequencing on the ground and in the air to reduce separations.
- To reduce noise and improve fuel efficiency, the turbofan engine and incremental gearing/bypass ratio enhancements have provided much of what has been needed.
- To manage increasingly complex and crowded airspace, the introduction of Transportation Management Associations (TMA), Global Positioning Systems (GPS), and Precision Area Navigation (R-NAV) have all found a role.
- To address terminal processing bottlenecks, the introduction of automated check-in and E-gates have been vital.
- To meet terrorist threats and hacking of digital systems, biometrics and cyber security have been expanded and enhanced.

2.0.3 But in the last decade, as access to aviation has become more ubiquitous, the industry is facing new and potentially paradigm-changing challenges that require revolutionary, rather than merely evolutionary new technologies.

2.1 The Industry Today

2.1.0 Air transport in the UK has changed from a sector that prior to the 1980s was largely in public ownership to a highly competitive industry in which private corporations provide the most prevalent form of ownership in the airline and OEM[14] markets – although some carriers in Europe and further East still have significant public shareholders. A similar trend has been seen in UK airports where operators are heavily privately invested, even though there is still some form of local and regional government interest in up to half of them. In most other countries in Europe and North America, state, city or community ownership remains predominant.

2.1.1 Private investment and increased competition in the airline sector have led to a strong focus on cost-cutting and (real terms) price reductions to drive passenger volume. This development has led to operations based on thin margins and price segmentation (unbundling) in search of increased profitability, market share and economies of scale. But while there are some well-known UK success stories such as easyJet and Jet2, there have also been numerous failures, with examples including Monarch, Thomas Cook and Flybe. Weaknesses included the inability to optimise new aircraft and online technology, as well as vulnerability to external shocks (e.g. fuel price spikes; conflicts; Covid19), which can be fatal for companies lacking scale or access to the latest technology.

2.1.2 In the airport sector there has been a similar story, although in the case of infrastructure capacity and operational efficiency size are king. Hence larger airports get larger and can afford the most modern technology to manage their operations, reducing marginal costs, while smaller ones cannot and become stalled in a no-man's land between rising regulatory costs and operational overheads – while unable to afford the investment in technology to move beyond small margins and losses to greater profitability and resilience.

2.1.3 Of course, technology alone is not responsible for individual airports' fortunes – catchment, surface access, the configuration of infrastructure and the cost of maintaining it are equally if not more important. However, historical changes in aircraft technology, improvements to air navigation, the introduction of renewables and the scope for adapting to new market opportunities (e.g. military or special mission roles, offshore rotary operations, aircraft testing and hosting commercial niches in an aircraft's life cycle) have all contributed to diversification of income and therefore greater financial security. And today, new technology is at the forefront of solutions to the industry's carbon footprint, reducing delays, improving the passenger experience, and helping to bring forward new modalities.

14 Original Equipment Manufacturer (e.g. Boeing, Airbus, Rolls Royce, GE, Prat & Whitney, Safran, Messier Douwty, Leonardo, Thales, BAE Systems).

2.1.4 And yet, despite the significance of private capital and governance in the industry's growth and technological change, Government remains deeply and inextricably involved. This is largely due to the absolute need to prioritise safety – public tolerance of death and injury in aviation is far lower than, say, for road traffic – which means tight certification of new products and key operations (e.g. air traffic control); the need to manage (ration) limited air space; and its international nature, which requires regional and global co-ordination roles which only Governments can fulfil. In addition, many Governments want to promote and encourage the industry in their countries, for economic and other reasons.

2.2 Current and Future Priorities

2.2.0 In order to provide a comprehensive overview of the priority issues facing the sector today, whilst simultaneously attempting to simplify a complex picture, we have developed the flowchart **Figure 1** (p.11 in the Executive Summary). Its aim is to help the reader track developments from the high-level external and internal influences that are the driving force behind many of the challenges the industry faces such as:

- Financial crises resulting in major economic recessions (e.g. 1999 and 2008-09).
- Long term geopolitical uncertainty (e.g. end of the Cold War, 9/11 attacks, various global conflicts, Brexit).
- Environmental hazard (e.g. pandemics and tectonic activity).
- Competitive pressures promoting consolidation and supressing innovation that could result in disruption.

2.2.1 The flowchart then highlights the most significant challenges facing the industry and the kind of interventions we expect will be needed. Finally, it foreshadows some of the technologies which may be able to contribute solutions. In this way the flowchart mimics the structure of the chapter and those that follow.

2.2.2 The first tier of Figure 1 identifies a range of strategic challenges under four themed columns, that the industry will wish or need to respond to in the coming decades:

- **A:** Environmental (Gold)
- **B:** Congestion and Declining Service Standards (Green)
- **C:** New Aviation Modalities and Associated Opportunities (Orange)
- **D:** Enhanced Security, Demand for Speed and Autonomous Operation (Blue)

2.2.3 The second horizontal tier of the graphic sets out the kind of interventions that are likely to be needed to address each of these challenges successfully; and the third tier identifies the emerging technologies that can potentially contribute to this under each of these themes.

2.2.4 The remainder of this chapter seeks to follow this broad structure as we begin to delve more deeply into the key challenges, and the opportunities, that are currently facing the industry. For the purposes of this review, although we also touch upon a number of 'other' or second tier issues in passing, we agreed with the ITC and its partner organisations[15] that the report should focus on three 'big ticket' challenges (A to C above), resolution of which are critical to the industry's prospects and what the experience of flying will be like in the future. These are also the strategic challenges on which the industry is devoting the most time and resources looking for technology answers.

15 The Civil Aviation Authority Innovation Unit and SASIG (Strategic Aviation Special Interest Group of the LGA).

2.3 The Core Strategic Challenges

Challenge A: The burden aviation is imposing on the environment

2.3.0 It is generally recognised that decarbonising aviation is seriously difficult because of its particularly intense use of energy and the lack of any readily available alternative to the use of kerosene at scale in the near future. Globally, aviation's share of climate change emissions is growing, even if the extent to which the UK is a material contributor to that problem is far less clear cut.

2.3.1 As other industries decarbonise, without major technological breakthroughs and investment in manufacturing capacity for alternative fuels, the Climate Change Committee (CCC) in its recent 7th Carbon Budget report[16] estimates the percentage of CO_2 currently attributable to aviation in the UK is 8% and likely to rise to closer to 30% in 2050[17]; making the industry visibly one of the larger and more laggardly carbon emitters nationally. Globally the comparative figures are much lower.

2.3.2 The industry's significance and profile, combined with scepticism about the industry's capacity to decarbonise, have already led to calls from environmental stakeholder groups for growth to be constrained through direct 'demand management' methods such as fuel tax, restrictions on airport capacity etc.

2.3.3 To address this fundamental challenge, the industry has developed a 'Net Zero Carbon Road Map'[18], which the Government's own strategy has broadly supported. All concerned recognise that delivering this in full to the proposed timescales will be extremely difficult. But failure would put the industry at risk of losing its 'social license' and put the UK at risk of breaking international commitments and statutory obligations, as well as losing its technological leadership in the field. Technologies to deliver the goals exist or are emerging, but the biggest challenges ahead are largely the financial and practical ones of investment and deployment, at speed and scale across the industry.

2.3.4 Airport noise and air quality are other environmental issues which cause great concern, particularly to local residents and communities near major airports. The noise generated by individual aircraft has reduced significantly over recent decades, but for local residents this may offer little comfort. Major airports are important economic centres in their own right, generating jobs and other opportunities – which in turn adds to pressures for additional housing in the vicinity. Night noise and sleep disturbance is a particular concern, and the Department for Transport (DfT) has launched a review of the issue. Local air pollution is largely generated by road traffic, so the main issue here – apart from a growing switch to public transport – is how to promote the decarbonisation of cars, lorries and buses.

16 Climate Change Commission – The Seventh Carbon Budget (Feb 2025).

17 Ibid – These projections include emissions from all outbound flights departing UK airports to all parts of the World, and are based on assumptions about passenger growth, Radiative Forcing effects and reductions in emissions from other sectors none of which are certain. The also rely upon the CCCs own view about the likely the rate of take up SAF by airlines serving the UK which are based on estimates of UK based SAF production. However, as a Sustainable Aviation (the body representing the UK industry as a whole) press release published the same day as the CCC's report points out, these ignore the potential for SAF to be imported into the UK from other parts of the world just as oil, gas and kerosene is today. All of which could mean the CCC's forecasts of aviation emissions over the next 5 years may be a little pessimistic.

18 Sustainable Aviation: Net Zero Carbon Road Map (2022).

2.3.5 Pressures for new housing in the vicinity of major airports adds to the number of people exposed to aircraft noise and the need for countervailing measures. While new Building Guidance may help developers to make their projects better adapted to these noisier environments, there are no breakthrough technologies that seem likely to eliminate aviation noise at source or allow it to be designed out in buildings altogether. For large airports located near significant urban populations continued growth in air traffic will bring the noise challenges outlined above into increasing focus in the coming decades.

2.3.6 With environmental challenges becoming more acute and the contribution of aviation to these becoming more significant, tackling them is now the industry's biggest challenge. There are many ways in which this might be done, including operational changes (flight paths, descents etc) as well as more fundamental changes to the way planes are powered and designed. Technology is crucial to such changes, and this report will discuss the main ones currently in prospect. But it is important to note that, if these operational and technology changes are not introduced successfully, the industry is likely to face growing calls for more direct restrictions on flights to be applied, with significant implications for future travel and connectivity.

Challenge B: Tackling Congestion, Delays and Inefficiencies

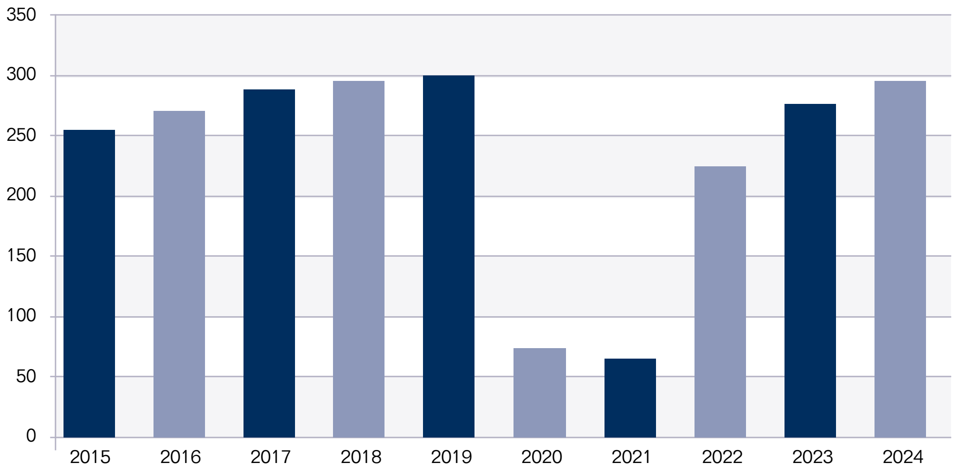
2.3.7 Where congestion (i.e. demand approaching capacity limits) begins to affect aviation systems, whether on the ground at airports, or in the air along busy corridors, in complex airspace, the impacts can become widespread and affect a range of stakeholders. These include:

- Passengers who experience delays and potential disruption to their journeys and a crowded and sub-optimal terminal environment.
- Airlines who face additional operational costs associated with crewing and fuel use, from delays and stacking.
- Airports who may lose revenue through penalties built into contracts with airlines, face a loss of confidence amongst airlines as a reliable partner and ultimately slot constraints curtailing future growth.
- Constraints, perceived or real, introducing limitations on local and regional connectivity impacting networks and frequency and therefore the contribution aviation can make to the wider economy, through constraints on local and regional connectivity.
- Key environmental externalities (e.g. carbon emissions, noise, air quality and adverse effects on surface transport conditions) will be intensified and potentially become more concentrated temporarily and spatially, increasing impacts on local communities and other sensitive receptors.

2.3.8 These are important issues that the industry must tackle to secure the social licence and political backing to grow, which in turn will impact on investor confidence and the way passengers perceive their travel experience and their willingness to engage with the industry in the future.

2.3.9 Hence the focus in the industry is on technologies that can help to reduce delays, improve reliability and enhance the travel experience for passengers and freight.

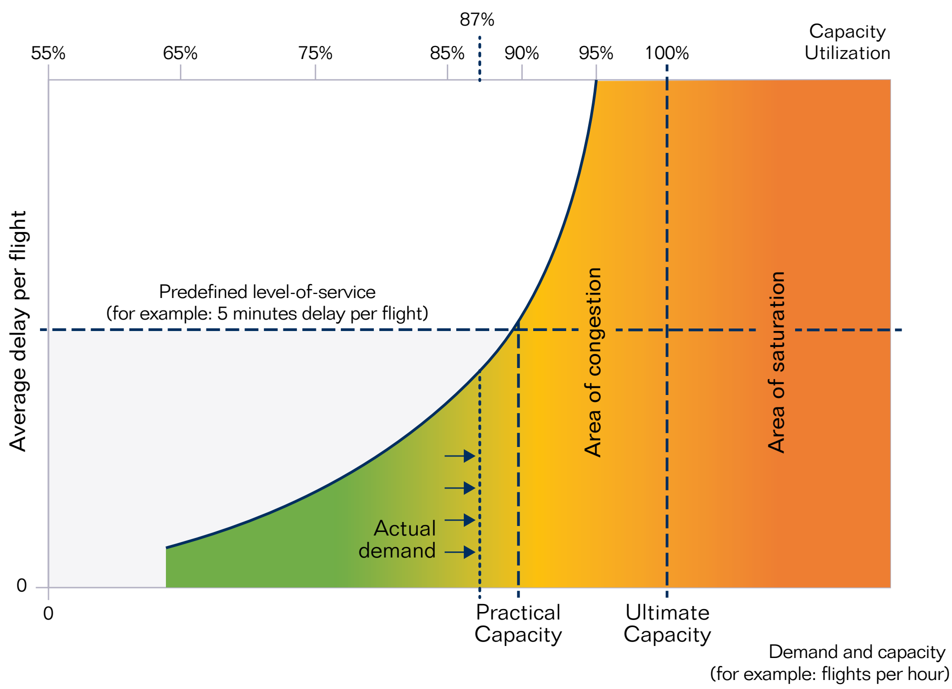
Figure 2: Terminal Passengers at Al UK Airports 2015-2024



Source: CAA Airport Statistics

2.3.10 Figure 2 above shows that passenger numbers bounced back quickly after the pandemic, reviving the challenges of constrained capacity in the air and on the ground. Figure 3 below illustrates how capacity limits, once hit, can lead to services deteriorating at an exponential rate.

Figure 3: Airport Capacity Utilisation/Delay Curve – Berlin Airport[19]



Source: Journal of the Korean Society for Aviation and Aeronautics (2020)

19 HyoJu Lee and DoHyun Kim: A Comparative Study of Delay Calculation Method on Airport Capacity – Journal of the Korean Society for Aviation and Aeronautics (2020).

Challenge C: Realising the potential of new modalities

2.3.11 This challenge is about seizing new opportunities, for novel forms of transportation and novel business opportunities, now becoming possible for the first time including better logistics in remote areas and last mile deliveries by drone, responding to enhanced demand and net zero inter-regional mobility opportunities, especially where rail and road networks are inadequate (e.g. in peripheral rural areas or where there is a market for orbital journeys but surface infrastructure is radial). The focus of this section in the report is about the opportunities for new services and new business models being opened up by innovative technologies, notably AAM (Advanced Air Mobility).

2.3.12 If UK aviation's record of constantly delivering transformative technological enhancements, which has kept it at the top of global industry across each of its sub-sectors (i.e. airlines, airports and aerospace) is to continue, then it will need to remain competitive in emerging new forms of urban, regional and logistical air modality and the near earth satellites sector.

2.3.13 Since World War II, as aerospace and air transport developed into major industries associated with advanced economies, UK Governments have consistently recognised that the scale of investment in research and development required to remain at the leading edge of aviation technologies, involves risks that often need fiscal, policy and regulatory collaboration between the public and private sectors – a pattern seen in most countries that have developed a significant market presence in the sector. We discuss later whether and how this approach may need to be taken forward in relation to the new technologies considered in the next chapter and how such engagement can best be adapted to meet the needs of the current and future innovation.

Other Challenges

2.3.14 There are other significant technology-related issues and challenges which are not discussed in detail in this report but which should be noted. They include:

- **Increased cyber threats** to critical security and safety systems.
- **Pressure on airlines and the wider industry to preserve aviation's key competitive advantages and market share relative to other modes.**[20] These include speed, greater product differentiation[21], more direct flights and denser network coverage, to promote national, international and inter-continental connectivity.
- **The need for airlines and airports to keep costs under control** in order to build commercial resilience and facilitate investment.

20 High speed trains for passengers and hybrid shipping (using sea for part of the journey then air) and long – distance overland rail (e.g. the New Silk Route from China to Europe) for freight.

21 Multiple types of aircraft for different journey purposes and the availability of more classes of travel (for passengers and freight) on scheduled airlines and the option of on demand personalised travel offered by Business Aviation, which neither rail or shipping can offer on longer distance journeys.

2.3.15 The most immediate of these is the threat of cyber disruption. However, the cyber threat is already being addressed actively through increased intelligence collaboration and technological evolution. But in the medium-term, competitive positioning and cost management are likely to loom much larger, especially where land use planning controls and fiscal measures are used to restrict capacity and price-off demand until it is in line with local, national and global targets for noise and carbon emissions.

2.3.16 In terms of technological advances, civilian aircraft capable of exceeding the speed of sound have again reached the prototype testing stage[22]; and generic digital technologies show promise in optimising flight routings and tackling congested airspace, to allow faster and more reliable air travel.

2.3.17 The industry is also placing considerable faith in digital technologies to help reduce aircraft maintenance costs, manage airport operations more efficiently and, ultimately to facilitate autonomous operations on the ground and in the air – even if this is likely to be beyond the time horizon adopted for this report.

2.3.18 In this chapter we've highlighted what can be seen as three priority challenges facing the industry over the next 25-odd years. Chapter 3 identifies the key technologies which seem to have the potential to address them. Then, in chapter 4 and 5 we highlight the wider commercial and policy priorities which need to be addressed, if they are to be deployed successfully and at pace.

22 Some 22 years after the last Concorde was withdrawn from commercial service.

3. New Aviation Technologies - Themes and Typology

3.0 Introduction

3.0.1 While there are many ways of categorising new Aviation Technologies (e.g. by type, by stage of development, by commercial prospects, by importance to UK plc, by potential scale of impact) for simplicity and clarity we have adopted a single typology which has then been applied consistently across the report. The themes reflect the high-level challenges that the industry in the UK needs to respond to, if it is to:

- remain at the forefront of innovation and embrace new modalities,
- be competitive and commercially successful,
- tackle reliability and resilience issues,
- maintain service standards and enhance the experience of air travel for passengers and cargo respectively, and
- achieve levels of sustainability that will enable it to keep its social licence.

3.0.2 As noted in Chapter 2, those priorities are:

A. Making aviation environmentally sustainable.

B. Tackling congestion, delays and inefficiencies.

C. Realising the potential of new modalities.

And as catch-all for other emergent technologies which form part of the new wave of innovation in aviation, but we will only touch lightly on:

D. Facilitating other forms of valuable technological enhancement.

3.0.3 We have reviewed a wide range of new or recent innovations and categorised them into eight which fall under the challenges, A to C, as illustrated in Table 1.

Table 1: Technology Typology Used in the Report

CHALLENGE A	CHALLENGE B	CHALLENGE C
Making Aviation Environmentally Sustainable	**Tackling Congestions, Delays & Deteriorating Services Standards**	**Realising the Potential of New Materials**
A1 Sustainable Fuels	B1 Airspace Modernisation	C1 Drones and AAM
A2 New Propulsion Systems	B2 Passenger Facing Technologies	C2 Satellite Launch and Hosting Platforms
A3 New Aircraft Design		C3 New Supersonic Civilian Aircraft

- **Group A** are technologies aimed at transforming the industry's long-term environmental sustainability.
- **Group B** includes technologies that can help to reduce delays, improve reliability and enhance the travel experience for passengers and freight.
- **Group C** comprises technologies capable of serving remote, rural, and urban environments better, the arrival of enhanced platforms for delivering, maintaining and decommissioning satellites in lower orbit and new aircraft capable of Mach 3 flight:

3.0.4 While this review focuses primarily on the technologies particularly relevant to challenges A-C, it also touches briefly on other related technologies (**Group D**) which impact on the aviation industry, notably:

- **D1**: Cyber Security.
- **D2:** Generic Enabling Technologies.
- **D3:** Autonomous Operations .

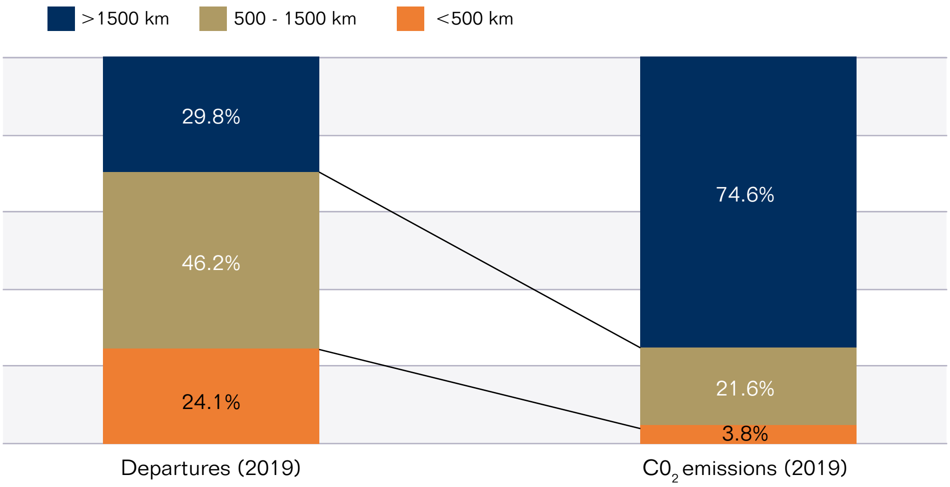
3.0.5 While Groups A-C are explored in more detail in subsequent sections of this chapter, those in Group D are examined further in Appendix C (available separately online – see p.137).

3.1 Group A: Making Aviation Sustainable

A1/A2: Sustainable Fuels and New Propulsion Systems

3.1.1 **Figure 4** below illustrates which flights generate the most CO_2 emissions. In Europe (including the UK) in 2019, although short-haul flights (500km or less) represented almost a quarter of departures, they generated only 4 per cent of CO_2 emissions. Conversely, long-haul flights (over 1500km), with about 30 per cent of departures generated 75 per cent of aviation's CO_2 emissions. It is also long range and wide-bodied aircraft serving such networks that are associated with greater noise emissions.

Figure 4: Share of CO_2 Emissions vs Length of flights in Europe (2019)



Source: Eurocontrol – Aviation Intelligence Unit, Think Paper 8

3.1.2 In considering the technologies needed to address the key challenge of sustainability, it is therefore essential to differentiate between those which can be applied to these differing flight categories.

3.1.3 Ultra-high bypass ratio (UHBR) engines represent the most advanced form of turbofan design for jet engines. They achieve this by maximizing the amount of air that bypasses the engine core, compared to traditional turbofan designs. Many also use a geared turbofan configuration, which allows the fan to spin at a slower, more efficient speed while also enabling the turbine to spin rapidly. The result is that fuel efficiency is increased while noise energy is diminished because of reduced jet exhaust velocity. UHBR also has drawbacks such as the greater size and weight of the engine, more aerodynamic drag, increased fan blade stress requiring the use of more expensive materials which in turn increases complexity and costs, but its key benefits appear able to make an important contribution to meeting two of the most important environmental challenges facing the sector.

3.1.4 So far as fuels are concerned, there are 3 main approaches to decarbonisation:

- Sustainable Aviation Fuel (SAF) made from either waste inventory, bio-feedstock, or synthetically from captured carbon, collectively referred to as a fuel that can be used as a ‘drop-in alternative’ in existing aero-engines.
- Electricity or hybrid electricity generated from batteries charged using renewable energy or hydrogen fuel cells, appropriately sized for the aircraft carrying them, which generate electrical power to turn turboprops or turbofans through a process of electrolysis.
- Hydrogen (or ammonia), injected directly into jet engines. However, because it has only a third of the calorific value of kerosene-based Jet A1 fuel, redesigned aircraft with much larger fuel tanks than conventional aircraft will be required.

Sustainable Aviation Fuel (SAF)

3.1.5 Of these alternatives SAF currently has 2 major advantages. First, it can be used with existing aircraft, so doesn't require fleet redesign and replacement. Second, it can be used for longer-haul as well as short-haul fights, unlike batteries which so far require too much weight to power long-haul flights. Since most CO_2 is generated by longer-haul flights, these make SAF the technology most likely to make a material difference in the next couple of decades.

3.1.6 Furthermore, SAF represents the most advanced option in terms of technological maturity. It offers a drop-in fuel solution that appears to require minimal modifications to existing engines or airframes and potentially offers an up to 80% reduction in carbon emissions compared to conventional kerosene. Regulators are taking a cautious approach to the level of blend they allow to be used for general (as opposed to trial) use, whilst the long-term condition of engines using SAF are monitored. Costs and the need to move progressively rather than overnight to using higher levels of SAF means that there will also be a transitional period when both new and legacy fuels and their associated infrastructure and storage systems will be required to operate alongside one another.

3.1.7 It is important to recognise that, although the carbon savings from SAF are prospectively significant – depending on the extent to which it is blended with traditional Jet A1 – SAF does not reduce the level of tailpipe emissions. Its value in terms of carbon emissions savings arises from the fact it uses renewable sources (various forms of household and agricultural waste, specialist crops and algae or entirely synthetic sources that use captured CO_2)[23], rather than releasing long-buried carbon into the atmosphere. Consequently, the most difficult task in the case of this technology is not innovation, prototyping, certification and industrialisation, but how to obtain truly renewable feedstocks at the volumes needed for large-scale use in aviation. And whilst SAF can be derived from a variety of sources and processes, the scale of both extant and projected future demand suggests SAF produced from biofuel and domestic waste, and even agriculture and forestry, will hit feedstock constraints very quickly. This means that as renewables and re-captured carbon become more plentiful, synthetic SAF (produced by hydrolysis using of green hydrogen generated by renewable energy and captured CO_2) will need to have its production scaled-up to the point where it becomes the dominant source of supply in the longer term.

23 The chemistry and process engineering behind different forms of SAF production are well understood – biofuels from organic/agricultural waste are the most advanced, followed by 'energy crops' such as jatropha, miscanthus, seaweed and algae grown specifically for the purpose and synthetic SAF derived from hydrolysis using hydrogen and captured carbon.

3.1.8 While pilot projects and micro-production facilities to generate SAF are emerging worldwide[24], at present large-scale facilities remain few and far between, both in the UK and internationally despite the need for SAF for the aviation sector alone (these fuels may also be capable of being used by other transport modes). This is because of the scale of the upfront development costs for large-scale facilities and the need for significant government participation in the form of risk-share. However, there is growing evidence that as in the UK this is being recognised in several other parts of the world as major initiatives are being brought forward, often with government support or through the agency of publicly owned energy companies[25].

3.1.9 Because SAF is technologically advanced, offers a 'drop-in' solution that is compatible with the existing aircraft fleet and for all types of flight (long haul as well as shorter distances), there is a a wide consensus in the industry that as by far the single most important contributor towards decarbonising the industry over the next 25 years.

3.1.10 However, it is not a magic bullet which can achieve net zero alone and there is a wide range of opinion about how big a contribution it can make by 2050. In 2020 the Climate Change Commission estimated that by 2050 SAF could contribute 8 $MtCO_2e$ of the 51 $MtCO_2e$ reduction required, whereas the previous Government's estimate in its Jet Zero high Ambition strategy was 13 $MtCO_2e$. These alternative views are significant because, whereas the UK industry believes SAF can provide 39% of the required reduction in CO_2 emissions by 2050, IATA – the global airline trade association – is looking to SAF to do 65% of the heavy lifting.

3.1.11 Moreover, under Sustainable Aviation UK's route map other forms of abatement (including offsetting and demand pricing) will only need to account for 13% of forecast emissions, whereas that figure is 37% under the Government's best view and over 50% if the Climate Change Committee's more pessimistic assumptions about technology take-up[26] are taken at face value.

3.1.12 Other 'models' for reduction of UK aviation emissions are less confident of the contribution SAF can make towards the industry's journey to Net Zero[27]. But whatever the eventual figure, and the contribution from other technologies and initiatives, there is consensus that SAF is the most urgent priority between now and the mid-century.

3.1.13 The importance of achieving this quickly becomes clear in Figure 5 and 6 below, where SAF is identified as being responsible for nearly 26 $MtCO_2e$ or 40% of UK aviation's required carbon reduction of by 2050, far higher than fleet upgrades with aircraft using other forms of fuels (i.e. electricity and hydrogen/ammonia) and more than 2.5x any other form of intervention.

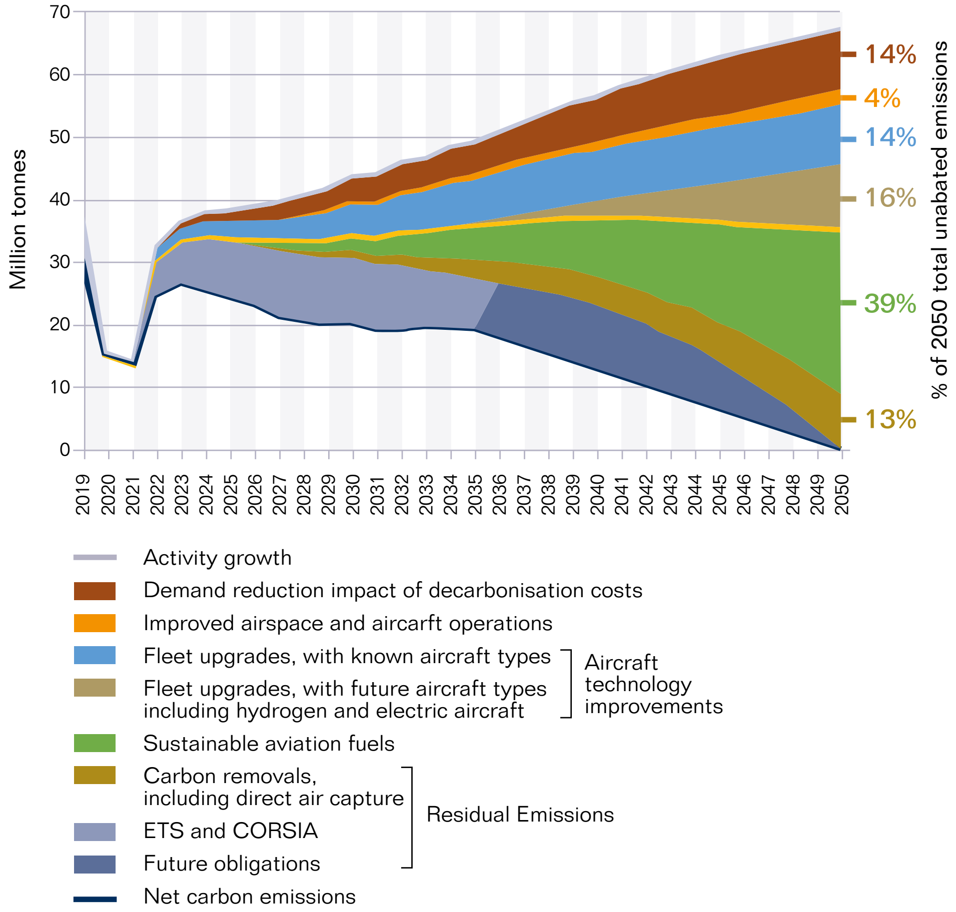
24 SkyNRG: Sustainable Aviation Fuel Market Outlook (June 2024).

25 Matthias Braun, Wolfgang Grimme, Katrin Oesingmann: Pathway to net zero – Reviewing sustainable aviation fuels, environmental impacts and pricing; Journal of Air Traffic Management (2024).

26 They exclude and government interventions to encourage it.

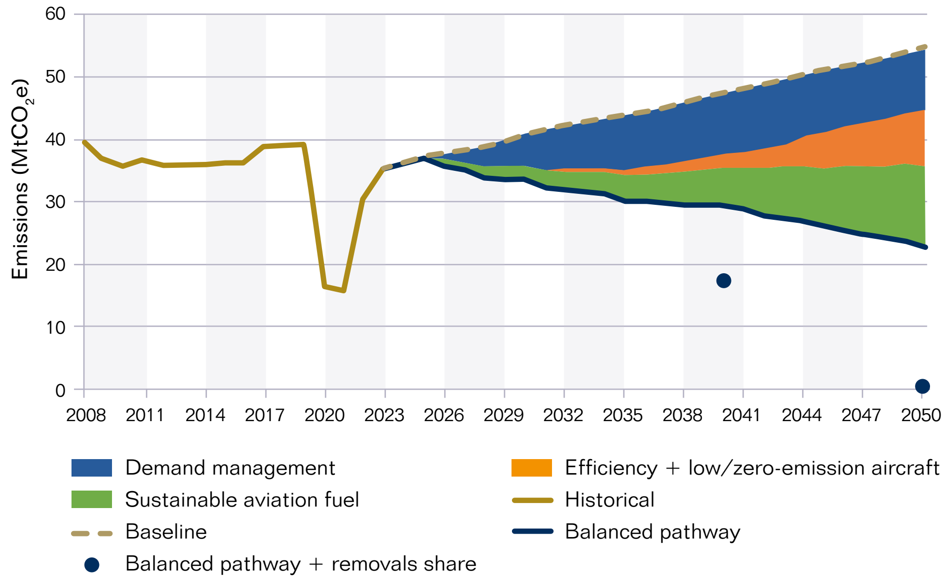
27 House of Commons Environmental Audit Committee – Net Zero and the UK Aviation Sector (Dec 2023).

Figure 5: Sustainable Aviation's estimate of the elements needed for aviation to achieve net zero carbon emissions by 2050[28]



Source: Sustainable Aviation

Figure 6: Pathway to reducing CO_2 emissions from aviation by the Climate Change Committee[29]



28 Source: Sustainable Aviation – Net Zero Carbon Roadmap Technical Report (June 2024).

29 Source: Chart 7.6.2 in Climate Change Committee Seventh Carbon - Budget Charts and Data in the Report (Feb 2025).

3.1.14 Despite the common view that SAF is likely to make an essential contribution to decarbonisation, Figures 5 and 6 above illustrate differing views about the speed and extent of its introduction, as well as differences about the prospects for other crucial improvements in aircraft design, operational improvements, carbon offsets and other measures. The Climate Change Committee's relatively pessimistic view is that technological and operational improvements are unlikely to suffice in the time available, and that more direct measures to constrain the growth of aviation – i.e. demand management – are likely to be needed as well.

3.1.15 The industry and Government do not accept such an intervention will be required on the basis that emerging technologies will produce more carbon savings and that abatement (i.e. carbon capture and off-setting) measures will be able to meet any gap that they are unable to fill.

3.1.16 The last government acknowledged this by setting up the Jet Zero Council, now revamped as the Jet Zero Taskforce, identifying the ultimate requirement for 14 SAF plants, providing small development grants totalling £180m towards two of them and by starting discussions about introducing a 'Contract for Differences' as a mechanism to offer the industry a risk-share approach in the form of a price guarantee mechanism. The incoming Labour government recognised the importance of these initiatives and immediately committed to a SAF Bill in the 2024 Kings Speech to take the necessary legislative powers to re-assure investors and ensure the best possible prospects for scaling-up of production; and to this end also confirmed the funding set aside for Breakthrough Energy Partnership projects.

3.1.17 It has also introduced the SAF Mandate, a UK government policy that requires fuel suppliers to blend a minimum percentage of Sustainable Aviation Fuel (SAF) into the aviation fuel they supply. The mandate starts with 2% use of SAF in 2025, rising to 10% in 2030, and 22% in 2040, with the obligation remaining at 22% until there is more certainty regarding SAF supply.

3.1.18 The critical importance of increased production and use of Sustainable Aviation Fuel in is understood by all parties, because there are prospectively some significant upsides from doing so that offer a range of benefits to many stakeholders. The benefits to the UK of a SAF industry has been estimated by the Government to generate between £700m-£1.6bn in GVA (Gross Value Added), to create between 5,000-11,000 green jobs, and can help reduce the UK's reliance on oil imports[30].

3.1.19 Although many major airlines have expressed interest in using SAF, both in the UK and internationally – and indeed some are already doing so – its widespread adoption also faces significant challenges such as securing agreement on standards, scaling up of supply, and reducing the cost of the end-product to a level the industry can afford. In mid-September 2025 an average gallon of SAF cost over four times more than Jet A1 fuel[31]; that kind of differential is commercially unsustainable.

30 DfT Net Zero Aviation Strategy (2022).

31 Source: x4.2 ratio quoted by IATA, S&P Global and Aviation Business.

Electric and Hydrogen-Electric Propulsion

3.1.20 The second of the clean fuel systems being actively pursued by the industry (in this case aircraft OEMs and engine manufacturers) are electric or hydrogen-electric power trains. These are typically associated with turboprop or turbofan engines, powered by batteries, with either hybrid engines or hydrogen fuel cells. Hybrid/fuel cells work by continuous recharging during flight from hydrogen, in the form of gas. This means that (unlike direct use of liquid hydrogen, discussed below) it can be stored on the plane in secure containers at normal temperatures; but it is much more limited in terms of the energy capacity than it may ultimately be possible to derive from direct use of liquid hydrogen.

3.1.21 Battery-supplied electrical energy for aircraft propulsion offers zero emissions and high efficiency in electric motors, leading to lower operating costs and quieter flights, while leveraging mature technology suitable for short-range, small aircraft like drones. However, its low energy density and heavy weight severely limit range and payload, making it impractical for large commercial planes, and long recharge times coupled with battery degradation add to operational and maintenance challenges. Overall, batteries excel in environmental and simplicity benefits but struggle with scalability and endurance for broader aviation applications.

3.1.22 Hydrogen fuel cell-supplied electrical energy provides higher energy density for extended range and zero carbon emissions with only water vapor as exhaust, enabling fast refuelling comparable to traditional fuels and potential scalability for larger aircraft. Yet, it faces lower overall efficiency due to energy losses in production and conversion, significant infrastructure hurdles for production and refuelling, and safety concerns from hydrogen's flammability alongside high costs. In summary, hydrogen fuel cells promise greater range and environmental advantages but are hindered by efficiency, infrastructure, and safety issues that limit current adoption.

3.1.23 To date the power output from the lithium-based batteries that are currently available is struggling to make battery-only propulsion feasible other than when used in small 2-4 seat aircraft[32], and even then, the projected sector lengths are likely to be short (typically no more than 250km). The SATE[33] project based in the Orkney Islands has paid particular attention to this aircraft/power unit configuration, as the aircraft needed to fly between the islands in the archipelago are small and the supply of renewable electricity from local wind power potentially abundant.

3.1.24 Although there have been some significant advances in battery technology, particularly in the motor vehicle sector, the greater energy demands of aircraft propulsion and the safety critical environment in which it must be reliably delivered means that some experts believe aircraft battery power is unlikely to grow significantly over the next ten years[34], so it is likely that battery driven aircraft will be restricted to close-in special mission operations, small private aircraft or e-VTOL operations. We will return to the AAM sector and its technologies later in this chapter, but here the focus is on small and regional turboprop passenger aircraft with between 9-50 seats and target sector lengths of up to 600km. For these kinds

32 Larger 9-19 seat aircraft are currently being trialled with hybrid or fuel cell-based power sources and it seems very unlikely that battery power alone will be capable of facilitating sector lengths of over 500km for the foreseeable future.

33 https://sate.scot

34 Graham Warwick: Mapping The Advanced Battery Landscape for Electric Aviation; Aviation Week (August 23, 2024).

of operations, the most realistic electric power train in the next ten years are hybrid-electric or hydrogen-electric (i.e. fuel cell) engines.

3.1.25 A good example of the application of these technologies, is a Swedish start-up leading the race with the 30 seat ES-30 (see **Figure 7** below) which will have a fully electric zero emissions range of 200 kilometres, and an extended hybrid-mode range of 400 kilometres with 30 passengers, with the flexibility to fly up to 800 kilometres with 25 passengers. Heart Aerospace has a total of 250 firm orders for the ES-30, with options and purchase rights for an additional 120 planes. Scottish regional airline Loganair are amongst its customers.

Figure 7: Heart Aerospace ES-30 In Loganair Colours

Source: Heart Aerospace

3.1.26 For Hydrogen-electric propulsion, Zero Avia are probably the most technologically mature provider of these types of units for fixed wing aircraft. They are working with Rolls Royce to retrofit different sizes of hydrogen-electrical power trains onto extant 9-19 seat aircraft for cross water (island hopping) and remote cross country Regional Air Mobility operations. However, they also have ambitions to fit their bigger power trains to 50 seat aircraft such as the ATR, which would make it suitable for commuter routes in North America and domestic and short cross boundary routes in Europe. Another high-profile start-up in this space is Heart Aerospace who are focused on a 30-seat aircraft design which is nearing commercial production and has orders from several airlines.

3.1.27 It is worth noting, however, that several other engine manufacturers (e.g. Holywell and Sarfan) and aircraft OEMs (Deutsche Aircraft, Embraer, Airbus/ATR and Bombardier) are all interested in the zero-carbon regional turboprop space. As a result the prospects for introduction of services with a zero-carbon offer using electrically driven propeller aircraft before 2030 look strong, especially as the additional power supply infrastructure that airports would need to invest in to recharge electric aircraft at airports will not be that material – although problems in securing an enhanced power supply from the national grid is being reported by many UK airports.

3.1.28 The above notwithstanding, it is also important to note that, similarly to SAF – and even if battery performance improves exponentially – the need for a renewable power source from which to charge them will ultimately still represent a significant bottleneck; and require dedicated local production or far better grid capacity than is currently available to many airports today.

100% Hydrogen Propulsion

3.1.29 Although hydrogen already has a position in the potential clean fuel mix through its role in fuel cell technology, there are much bigger ambitions for hydrogen across the aviation sector, starting with transit buses and airside vehicles, through regional propeller aircraft powered by fuel cells (as discussed above), and ultimately to narrow bodied jet aircraft capable of flying short and medium haul sectors using gas-turbine jet engines modified for hydrogen. Backed by EU research funding, Airbus has had the most ambitious hydrogen propulsion programme of any of the world's leading aircraft OEM's or engine manufacturers.

3.1.30 As a result, the push to develop hydrogen-powered planes has in recent years become a key part of the aviation industry's bid to eliminate carbon emissions, especially in Europe where the aviation industry predicted in 2021 that hydrogen would power a fifth of all plane journeys by 2050, but also latterly in the UK (the Hydrogen Alliance).

3.1.31 But in Q1 2025, the potential of hydrogen as a future fuel source fell suddenly and dramatically out of favour[35], as European airlines and manufacturers drastically downgraded their target for the contribution of hydrogen to their goal of reaching net zero by 2050. Then Airbus, the world's biggest plane maker, put the industry's most advanced programme for developing a hydrogen-powered passenger aircraft on hold. Boeing, always a comparative sceptic, has meanwhile also confirmed that it sees little or no role for hydrogen in decarbonising its own jets for decades at least.

3.1.32 Asked whether the industry would be dependent on SAF beyond 2050, Airbus CEO Guillaume Faury replied:

"Yes, of course, way beyond". He added: *"Hydrogen is an energy that will become sizeable and meaningful in the second half of the century, not in the first half. But it is not going to be the solution for the next 20 years... the need to cool and store hydrogen in a liquid state at -250C, and modify an aircraft to accommodate that, continued to present a challenge*.[36]

35 Hydrogen has proven far harder to harness commercially than first hoped:

a. For use in a plane, it must be cooled to -250C to turn it into a liquid and then stored at that temperature on board. Making this work for commercial aviation has proved very difficult.

b. Producing hydrogen at the scale needed by the aviation industry requires huge investment in electrolysis, liquefaction plants, gas pipeline networks and liquid hydrogen distribution, storage and refuelling infrastructure. This brings problems such as hydrogen embrittlement hydrogen molecules squeeze in between the metal crystals in pipework and eventually cause cracks which will result in leaks, fire or explosion. Pipes networks, national and local, might need to be replaced every 10 years.

c. To create truly green hydrogen, it must also be synthesised using clean electricity generated through renewables.

36 Hydrogen planes were meant to deliver Net Zero – now those plans are being torn up (Daily Telegraph, 19 Feb 2025).

3.1.33 A recent update, commissioned by trade bodies representing European airlines, airports, aerospace manufacturers and air traffic controllers[37] said hydrogen planes would now be responsible for just 6 percent of the required CO_2 reduction, down from the 20pc forecast in 2021. The study still anticipates that hydrogen planes will debut by 2040, but cautions that should their introduction recede further, *"only a marginal contribution by 2050 remains"*.

3.1.34 As well as downgrading the role of hydrogen, the European aviation industry has radically scaled up its estimated cost of reaching net zero. It has jumped by 50pc to €1.3 trillion as a result of the scarcity and inflated price of SAF, something the industry couldn't hope to fund from its own resources, the report says.

3.1.35 It is understood that Airbus sought to reassure members of the Hydrogen in Aviation (HIA) alliance of its commitment to the technology at a meeting in March 2025. HIA brings together UK players including Rolls-Royce and easyJet, which have been collaborating to develop a hydrogen-burning engine[38].

3.1.36 EasyJet said it has already pushed back its own expectations for a hydrogen plane to 2040 but remained committed to advancing the technology. Another HIA member, ZeroAvia, has been working on fuel cells that turn hydrogen into electricity through a chemical reaction. The energy produced is limited, however, with the company's initial ZA600 engine designed to power a plane with no more than 20 seats.

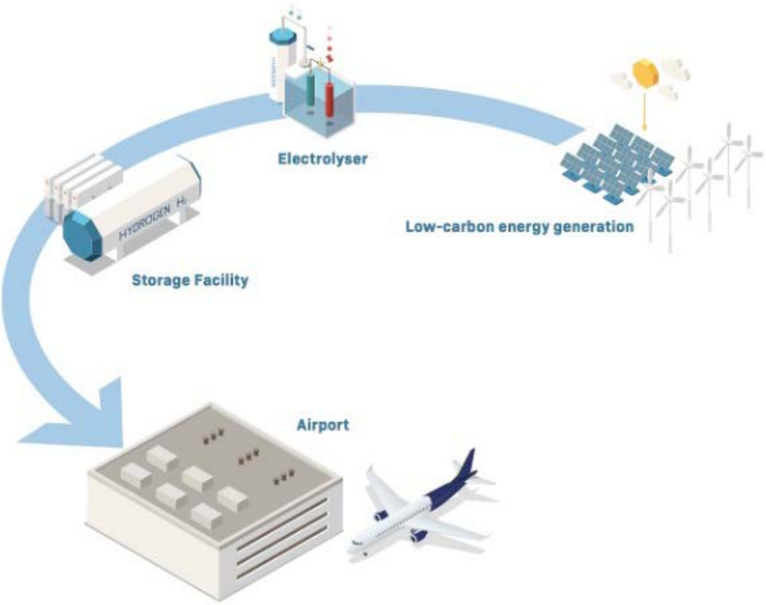
Hydrogen Fuel – Supporting Airport Infrastructure and Maintenance

3.1.37 Like SAF, one of the key impediments to the uptake of hydrogen-based aviation, whether using fuel cells or direct burn jet engines, is the need for a large supply of green energy and an entirely separate infrastructure to store and upload hydrogen at different sizes of airport; these represent significant hurdles that will need supportive policy if they are to be overcome. The cost and complexity of building the manufacturing plants, pipelines and specialist tanks that are needed will require a secure supply chain at each stage of the process – i.e. energy generation, hydrogen production, storage, and fuelling. Figure 8 below provides a conceptualisation of the ecosystem required to support a hydrogen fuel cell driven propulsion supply chain, ending at an airport where it can be uploaded to a suitable adapted plane.

37 Destination 2050: A Route to Net Zero European Aviation (Feb 2021).

38 Rolls Royce Press Release: Rolls Royce and easyJet set to perform testing at Nasa's Stennis Space Centre in Mississippi – summer 2025.

Figure 8: H_2 Hydrogen Aviation Ecosystem



Source: Hydrogen in Aviation

3.1.38 Supported by EU funding, Lufthansa Technik are taking the concept one stage further, by leading a demonstration project examining the infrastructure, ground processes and maintenance that will be required to support hydrogen-powered aircraft at airports when they are eventually introduced. The Hydrogen Aviation Alliance has forecast rising demand for narrow body hydrogen powered aircraft from 2040 to 2050,[39] although recent announcements by Airbus and cuts to research programmes in the US by the Trump administration mean this timeline is likely to move 5-10 years to the right.

Department for Transport Jet Zero Strategy 2022 Milestone Visualisation

3.1.39 If we take a high-level view of these competing clean fuel and propulsion technologies, it is evident that the most advanced is SAF; and given its 'drop-in' potential and ability to be used in all types of existing commercial aircraft[40], this is where the industry is currently focusing much of its attention. To date the UK government has followed the industry's lead in its interventions, with financial and now legislative support for SAF; however, it has also continued to support research and development work on electric powertrain systems with batteries and hybrid (conventional and hydrogen fuel cells) as a power source. Whilst it is not supporting holistic development programmes based on hydrogen flight in the way that has happened elsewhere, it is supportive of UK companies who are part of international consortia developing new aircraft and engine concepts and is invested in the process of scaling-up the manufacturing capacity for hydrogen fuel in the UK. This positioning is reflected in government's Jet Zero Strategy, which has five phases, which are designed to be cumulative in their effects.

39 Hydrogen in Aviation – Launching Hydrogen Powered Aviation (2024).

40 Only GA aircraft, that have piston engines, have to use aviation gasoline (AvGas).

3.1.40 The strategy starts by building upon the many areas in which innovation has been seeking to maximise the efficiency of existing aviation, moving to net zero targets for SAF based aviation, then hybrid-electric, and a combination post 2040 of zero-carbon (i.e. hydrogen-based) and zero-emissions[41] (i.e. battery electric) aviation. Some of the issues with this approach are considered in Chapters 5 and 6, but fundamental to its success will be the speed and cost that SAF can be supplied at, the sector lengths possible using electric and hydrogen propulsion and the cost of designing new aircraft, getting them certified and rolled out commercially. The aviation fuel mix of the future may, therefore, look much less uniform than today where, with the exception of GA piston driven aircraft, all types and sizes use the standard form of kerosene (Jet A1).

3.1.41 Given the uncertainties surrounding which energy source will be best suited to which type of aircraft and the timeline in which it will be available at airports at scale, a leading airline's view on how this mix of fuel/propulsion options may ultimately play out is interesting; not least because they are likely to have substantive direct interest in the outcome:

"The simple answer is we don't like complexity, but we also don't see a way around it because we have decarbonization targets as an airline and an industry that are going to make our business a bit more difficult".

"Electrification will come at the small end of the aircraft market while hydrogen comes into its own in fuel-cell powertrains for regional [and short haul] aircraft."

"For the kind of aircraft we operate, you're really looking at hydrogen combustion. We see SAF as the mainstay for the widebody market". (Lahiru Ranasinghe, easyJet Head of Net Zero).[42]

3.1.42 The airline sector's view of SAF is key to its exploration of hydrogen[42a].

"We see hydrogen as very complementary with SAF for the long-term decarbonization of this industry,"

"But a massive proportion of the SAF needed to decarbonize aviation will have to come from power-to-liquid fuels, which require green hydrogen and carbon capture".

"All the work we've done with our partners indicates that the direct use of hydrogen in liquid form, from an energy ecosystem perspective, is significantly more efficient than using it as a component of a power-to-liquid SAF".

3.1.43 Additionally, as narrowbody operators move toward hydrogen, this will ease the pressure on SAF supply chains and allow more of that fuel to be freed up for the widebody and long-haul market, helping to decarbonise the whole aviation sector.

41 Battery electric aircraft won't produce any contrails or other forms of emission whereas direct hydrogen burn will emit H_2O and in the right atmospheric conditions give rise to contrails.

42 Graham Warwick: Why this Budget Carrier Says Hydrogen Is Key to Sustainable Aviation, Aviation Week Network (April 2024)

42a Ibid.

Noise implications

3.1.44 As indicated earlier, there is no single game-changing technology that offers the prospect of a transformational solution to the industry's noise challenge. Several target noise reductions at source (UHBR engines[43], Helmholtz resonators[44] and Active Noise Control[45]), while others focus on the airframe and operational procedures. The Table below summarises the latest initiatives, but until these technologies become mature, greater emphasis will be needed on mitigation through a combination of allowing noise contours to influence land use planning, operational procedures – e.g. runway alternation, offset thresholds and Precision Area Navigation (P-RNAV) departure routings, and improved noise insulation standards in new buildings.

Table 2: At Source Noise Reduction Technologies

Technology	Noise Reduction (dB/EPNdB)	Application	Timeframe	Notes
Engines				
Ultra-High Bypass Ratio (UHBR) Engines	~10 EPNdB	Engine (new aircraft)	Mid-term (10–20 years)	Reduces jet noise via lower exhaust velocity; in development for next-gen aircraft (e.g., Airbus A321neo).
Helmholtz Resonators	5–10 dB (tonal noise)	Engine nacelles	Near-term (5–10 years)	Passive damping of fan noise; scalable for current fleets.
Microjet Injection	3–5 dB (potential)	Engine (future designs)	Long-term (20+ years)	Active control disrupts turbulence; requires complex integration.
Active Noise Control (ANC)	Up to 15 dB (specific conditions)	Cabin/engine (future)	Mid-term (10–20 years)	Primarily for cabin; external application under research.
Airframes				
Landing Gear Fairings	3–5 dB	Airframe (retrofit/new)	Near-term (5–10 years)	Smooths airflow; proven on Boeing designs.
Slat/Flap Redesign	2–4 dB	Airframe (new designs)	Mid-term (10–20 years)	Reduces turbulence noise; tested via Airbus ANTC.
Over-Wing/Mid-Fuselage Nacelles	30–40 dB (potential)	Airframe (new designs)	Long-term (20+ years)	Shields ground from engine noise; requires structural redesign.
Hybrid Wing Body Designs	40–50 dB (potential)	Aircraft design	Long-term (20+ years)	Integrates engines for noise shielding; NASA target for 2031.
Electric/Hybrid-Electric Propulsion	~20–30 dB (small aircraft)	Propulsion (regional jets)	Long-term (20+ years)	Near-silent for small aircraft; not yet scalable for large jets.
Operations				
Continuous Descent Approaches (CDA)	5–10 dB	Operational	Near-term (5–10 years)	Reduces engine thrust during landing; widely adoptable.
Optimized Flight Paths	Variable (up to 10 dB)	Operational	Near-term (5–10 years)	Routes flights over less populated areas; SESAR 3 trials.
Ground Power Units (GPUs)	5–10 dB (ground noise)	Ground operations	Near-term (5–10 years)	Replaces noisy APUs at gates; already implemented.

Source: Compilation by Northpoint Aviation

43 UHBR stands for Ultra High Bypass Ratio – this type of turbofan aero engine turbofan engine is designed for greater fuel efficiency by using a significantly larger fan that moves more air around the core of the engine reducing fuel consumption and engine noise.

44 Helmholtz resonators are a form of acoustic device that function as a mass-spring system to absorb or generate sound at a specific, narrow-band frequency.

45 Active Noise Control is a technology that uses microphones to detect ambient sounds and a processor to generate an "anti-noise" sound wave that is the exact opposite, or phase-inverted, of the original noise. When the two waves meet, they cancel each other out, a process known as destructive interference, resulting in significantly reduced background noise. ANC is at its most effective against steady, low-frequency sounds, such as airplane engines.

3.1.45 Electric and electric-hybrid aircraft are expected to produce significantly less noise than conventional turboprop and jet aircraft. Electric motors are inherently quieter than combustion engines, as they lack the loud exhaust and mechanical vibrations of jet or turboprop engines. For instance, electric aircraft like the Pipistrel Velis Electro generate noise levels around 60-65 dB during take-off, compared to 80-90 dB for small turboprops or jets. Hybrid systems, combining electric motors with smaller combustion engines, also reduce noise by relying on electric power during noise-sensitive phases like take-off and landing. Distributed electric propulsion, with multiple smaller motors, further disperses and reduces noise compared to the concentrated roar of traditional engines.

3.1.46 Hydrogen aircraft, particularly those using fuel cells, are also quieter than conventional aircraft but may not match the noise reduction of fully electric systems. Fuel cell hydrogen aircraft produce noise primarily from airframe and auxiliary systems, as the fuel cell itself is nearly silent, potentially cutting noise levels to 70-75 dB for similar operations. However, hydrogen aircraft using combustion engines (e.g., burning hydrogen in modified jet engines) may have noise levels closer to conventional jets, around 85-95 dB, due to similar exhaust dynamics.

A3: New Aircraft Designs

3.1.47 Putting aside the engines/propulsion systems, which are often a significant influence on aircraft design, then there are 3 elements which play an important role, in delivering better fuel and concurrently environmental performance:

- New Materials
- Enhanced Wing Design
- Innovative Airframe Designs

3.1.48 This section takes a brief look at the latest development in each of these areas in turn, before presenting some of the most innovative designs be under consideration by the industry. The projected timescales for their introduction can be found in Chapter 4.

New Materials

3.1.49 Materials are a focus for innovation for a number of important reasons, including strength, flexibility, cost, weight and laminar flow coefficients, which have a significant impact on drag. Since the turn of the century there has been a major focus on the use of composites in aircraft design, primarily on cost and weight grounds, but also because they are capable of being moulded accurately into complex shapes. More recently new composite alloys are being trialled, which have many of the beneficial characteristics of composites but without their frangible and recycling issues. Currently the focus is on high performance laminar flow materials (so called ‘Blade’ technology[46] after the name of EU Horizon programme that sponsored research into it), which has the valuable attribute of generating less frictional drag across the surface of the aircraft, improving lift and reducing fuel consumption relative to current materials.

46 Airbus (2017): https://www.airbus.com/en/newsroom/press-releases/2017-09-airbus-blade-laminar-flow-wing-demonstrator-makes-first-flight

Enhanced Wing Designs

3.1.50 As a primary source of lift (speed, air pressure and external climatic conditions being other important factors), wing design has received a lot of attention from OEMs since the early 2000s, once wide-bodied aircraft and engine design in the form of high bypass turbofans had allowed major advances in payload, speed and fuel efficiency.

3.1.51 The most notable initial improvement was the addition of winglets providing 2-3% fuel efficiency, but then a whole series of improvements were gradually introduced including:

- Additional wing flex once airborne using new composites and alloys
- Increased length relative to total area
- Improved aspect ratio
- Finely tapered and curved wingtips
- Continuously optimised wing twist

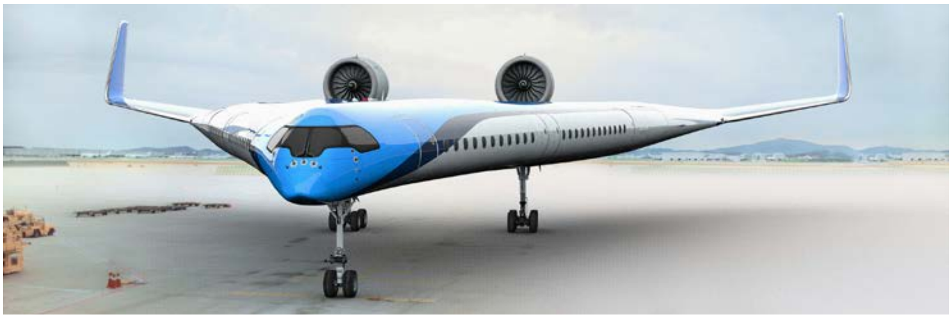
3.1.52 The result is a substantially optimised solution, as seen on the A330-800 and 900 which currently represent the best wing design in operation. But research is continuing, with NASA and Boeing focused on improving aspect ratios, potentially including the use of struts (see Figure 9 below).

Figure 9: High Aspect Ratio Aircraft with Truss Braced Wings[47]

Source: NASA

Others are moving towards increasing use of swept, canard or even delta wing solutions. One particularly radical approach in this category is the V-Wing design, in which passengers sit in both arms of the aircraft and where they conjoin, a concept derived from Delft University, which has already been developed into a prototype trialled by KLM (see **Figure 10**).

Figure 10: V-Wing Aircraft Design[48]



Source: KLM

47 Taken from: A Timeline of the Truss Braced Wing – Aviation Week Network (7 February 2020).

48 Source: CE Delft-KLM.

Mainframe

3.1.53 Meanwhile, JetZero, who have been working with the US Air force on Blended Wing Body (BWB) aircraft, are reported to be aiming for a full-scale commercial demonstrator by 2027[49]. This design concept involves a major departure from the traditional tube-based mainframe used in civilian aircraft and towards the full Blended Wing Body (BWB) concept that has been pioneered by the B2 stealth bomber. Both NASA and Airbus are working on civilian variants as part of their future commercial aircraft programmes. The BWB form minimises the total surface area of the aircraft skin, thus reducing skin drag to a minimum. It also creates a thickening of the wing root area, allowing a more efficient structure and reduced weight compared to a conventional craft. There are also plans to integrate Ultra High Bypass (UHB) ratio jet engines (the apogee of current aero-engine design) with the hybrid wing body to produce an aircraft with materially better aerodynamic efficiency, 10% improved fuel efficiency and lower noise outputs[50].

3.1.54 The BWB's integrated shape shown in Figure 11 below also offers opportunities to carry more fuel than a conventional aircraft, mainly stored in the wings, something that may become significant once hydrogen becomes commercialised as an aircraft fuel. However, the BWB's wider wingspan has an important disadvantage, being incompatible with some existing airport infrastructure where they don't have full Code F[51] stands or the capability to make them even wider.

Figure 11: JetZero – Blended Wing Body Concept

Source: Courtesy of and ©JetZero

49 Source: Simple Flying 6.3.25.

50 NASA audio simulations show a 15 dB reduction of Boeing 777-class aircraft.

51 IATA Design Code for stands capable of accommodating wide-bodied aircraft.

Radical New Aircraft Concepts

3.1.55 These jet powered aircraft are not the only radical new concepts under development. In a subsequent section of this chapter looking at AAM we discuss e-VTOL aircraft, but another good example is the Airlander Airship concept to be developed at an assembly site near Doncaster and used initially for freight or tourist overflight purposes[52]. Production is expected to be underway in the next 2-3 years with airships coming off the production line at 2-3 per month by the end of the decade.

3.1.56 Airlander is a hybrid-lift airship designed in Bedford that uses a combination of buoyancy, aerodynamics and vectored thrust to achieve lift. Due to the hybrid-lift philosophy, Airlander aircraft burn significantly less fuel than traditional aircraft which require much greater thrust to generate lift. This technology is theoretically capable of reducing carbon emissions by 90% when compared to a typical short-haul aeroplane. Vectored engines are necessary to provide additional lift and manoeuvrability closer to the ground during landing and take-off. While these currently run-on jet fuel, HAV have partnered with Collins Aerospace and University of Nottingham to develop electric engines for future use. Potential markets are listed as short-haul travel, tourism, freight and logistics and communication and surveillance roles.

Figure 12: The HAV Airlander Airship

Source: IanC66/Shutterstock

52 BBC News: Doncaster giant airship plant to create 1,200 jobs (March 2024); https://www.bbc.co.uk/news/uk-england-south-yorkshire-68639876.

Noise implications

3.1.57 High aspect ratio, V-shaped, and blended wing body (BWB) airframe designs generally offer noise reduction benefits compared to conventional jet airframe designs, but the extent and specifics vary:

- High Aspect Ratio Wings: These wings, with a greater length-to-width ratio, improve fuel efficiency and reduce engine power requirements, leading to lower engine noise. However, they may increase airframe noise at high angles of attack due to increased lift-induced drag, though overall noise is typically lower than conventional designs.
- V-Shaped Wings: These designs, often seen in configurations like flying wings, can reduce noise by optimizing airflow and reducing vortex shedding at wingtips. Their unique geometry may also shield engine noise, but they can generate higher noise during take-off and landing due to complex aerodynamic interactions.
- Blended Wing Body (BWB): BWB designs integrate the wings and fuselage, reducing drag and engine noise through better aerodynamic efficiency. They can also shield engine noise by embedding engines in the airframe, significantly lowering community noise levels compared to conventional tube-and-wing jets.

3.1.58 All three designs therefore tend to reduce engine-related noise due to improved aerodynamics and efficiency. BWB offers the most significant noise reduction, followed by V-shaped and high aspect ratio wings, though specific conditions (e.g. flight phase) can influence outcomes. Conventional jet airframes generally produce higher overall noise due to less optimized aerodynamics and exposed engine placement.

3.2 Group B: Tackling Congestion, Delays and Inefficiencies

B1: Airspace Modernisation

3.2.1 In this section of the report, attention is turned to technologies that respond to Category B industry challenges, namely those giving rise to congestion delays in the sky or at airports and/or deteriorating travel experience for air passengers and shippers of air cargo. Timescales associated with the introduction and market maturity of these technologies are discussed in Chapter 4.

3.2.2 In paragraph 2.3.7 we outlined the potential significance of congestion and delays on the aviation ecosystem and its key participants. International airspace, particularly in Europe, is heavily fragmented, with Air Traffic Management (ATM) divided across multiple national jurisdictions and over 30 ANSP (Air Navigation Service Providers) engaged in managing relatively small portions of airspace, leading to inefficiencies in flight paths, costs, and environmental impact. Initiatives like SES[53] and SESAR[54] aim to unify and modernize ATM, but political, technological, and economic challenges slow progress toward the desired end-state of a seamless European airspace. These problems impact upon UK air operations because the majority of UK flights depart into European airspace. The UK's own airspace is also in need of comprehensive modernisation, something which the UK Government has recognised and is actively progressing with CAA, NATS and the wider industry.

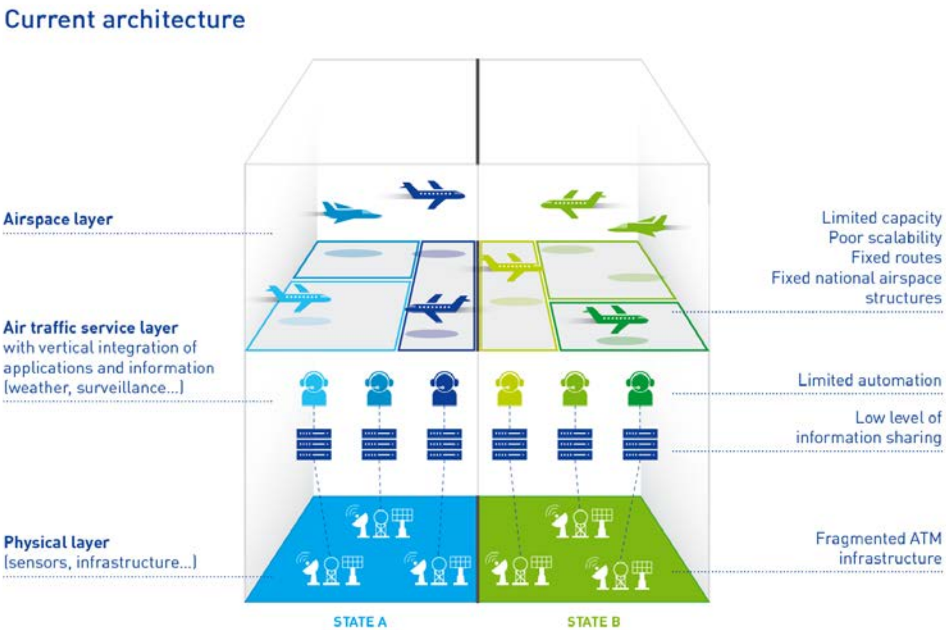
53 SES: Single European Sky.

54 SESAR: Single European Sky ATM Research.

3.2.3 A series of important technological tools are seen as key to future airspace management and are air navigation systems and being introduced over the next ten years (e.g. universal conspicuity[55], GNSS[56] and precision P-RNAV[57]). These collectively will allow better operational performance that will reduce flight delays and free-up air traffic control capacity, the shortage of which is a major constraint on airport capacity and an underlying cause of delays.

3.2.4 Technology delivering enhanced conspicuity and greater cockpit-based navigation will help to facilitate deconfliction and the use of airspace more efficiently, increasing the airspace capacity that is available and allowing new forms of computer-based guidance and automation to tackle the constraints listed on the right-hand portion of Figure 13 below[58].

Figure 13: Likely Change to Airspace Architecture



Source: courtesy of and © SESAR Joint Undertaking

Air Navigation Systems and ATC Architecture

3.2.5 Key to unlocking these constraints is a range of new Air Navigation and Air Traffic management technologies which are discussed below. They, in turn, are heavily dependent on the emergence of a range of generic digital technologies such as automation, robotics, 5G, Artificial Intelligence (AI), machine learning, and quantum computing. We can see their importance when we consider how they contribute to important platforms such as enroute navigation, airspace design and air traffic management. Some key examples of where these are applied are outlined below.

55 Universal Conspicuity: A system where all aircraft and uncrewed aircraft systems (UAS) operating in an airspace are electronically visible and detectable to each other.

56 GNSS: Global Navigation Satellite System.

57 P-RNAV: Precision Area Navigation is a European standard for Area Navigation (RNAV) in terminal airspace in which aircraft use using higher integrity navigation data to increase track-keeping accuracy to facilitate more efficient and safer flight paths (e.g. continuous descent approaches, optimized departure routes).

58 SESAR: European ATM Master Plan (2020).

3.2.6 Remote Virtual Towers (RVT) are a relatively recent technological solution being used to enable aerodrome air traffic services to be provided from a location some distance away from the airport's physical control tower. This is achieved through advanced technology like high-resolution cameras, sensors, and robust communication networks that transmit real-time visuals and data to controllers located elsewhere. London City is one of the few substantial airports that have adopted RVT, which offers benefits such as increased efficiency, cost savings, and enhanced safety, especially for smaller and medium-sized airports.

3.2.7 Precision Area Navigation (P-RNAV) is an established technology that is gradually being rolled out at major airports both within and outside the UK. It facilitates more efficient and flexible flight operations, particularly in busy terminal airspace, by enabling aircraft to fly more precise departure routes and approach paths. This optimises the use of runways, leads to reduced holding times, better traffic flow and, where airspace is particularly busy, lower fuel consumption and emissions.

Enhanced Digital Environment

3.2.8 High-speed 5G networks facilitate faster data exchange between aircraft, ground control, and other aviation systems, supporting real-time decision-making and greater automation. Early deployments have begun, with widespread use anticipated by 2025-2028.

3.2.9 Next-generation digital information management systems, which are actively used by both air traffic controllers and pilots, share and integrate real-time aeronautical information (e.g. weather updates, airspace restrictions and flight path changes) will be enhanced by 5G and satellite upgrades and thus reduce manual workloads for both controllers and pilots. Gradual implementation is ongoing, with widespread adoption anticipated by 2030 in the USA but not until 2045 in Europe[59].

3.2.10 Collaborative Decision-Making (CDM) platforms facilitate enhanced collaboration between airlines, airports, and air navigation service providers by sharing real-time data about gate turnaround times, optimised airspace and bottlenecks in the air traffic system, which will enable more efficient resource management. The roll out of CDM platforms is well underway across Europe's largest airports and is expected to reach full maturity as envisaged by SESAR (back in 2020) very soon[60].

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59 Date estimated for the full implementation of the Digital European Sky under the SESAR Joint Undertaking's ATM Masterplan.

60 Eurocontrol: Total Airport Management; https://www.eurocontrol.int/project/total-airport-management#:~:text=At%20the%20end%20of%20Wave,SESAR%20Digital%20Sky%20Demonstration%20process.

Enhanced Satellite Navigation Systems

3.2.11 The next-generation of satellite navigation systems, such as Europe's Galileo, the USA's GPS and the UK's own independent SBAS[61] initiative, will provide ultra-precise positioning and navigational capabilities for aircraft during takeoff, landing and en-route operations. These systems will enhance flight safety and efficiency by allowing more aircraft to operate in the same airspace; while also reducing the reliance on traditional ground-based navigation aids. Some advanced navigation capabilities, including GPS and Galileo are already in use[62], but will improve significantly as updated modules come online between 2025-2027 and reach their full potential in the 2030's.

Artificial Intelligence (AI) in Air Traffic Management

3.2.12 AI-driven systems using machine learning will be able to assist ACTO's in making faster, more informed decisions by analysing vast data streams to predict traffic patterns, identify potential conflicts, optimise flight routes, and prevent bottlenecks, thereby enhancing capacity management and reducing congestion during peak hours.

3.2.13 Artificial Intelligence has the potential to play a transformative role in Air Traffic Management (ATM) by enhancing efficiency, safety, and sustainability. It is expected to achieve this through several key applications:

- Automating routine tasks such as flight plan processing and communication, allowing air traffic controllers to focus on critical decisions. This increased automation supports workload reduction and operational efficiency. It also enables vast datasets from radar, weather, and flight plans to be analysed rapidly to provide real-time decision support for air traffic controllers.
- Forecasting air traffic demand and identify bottlenecks, enabling dynamic airspace management and the optimisation of arrival and departure sequences, minimizing holding times and fuel consumption. Machine learning models can help predict potential conflicts and optimize flight routes, reducing delays and improving airspace capacity.

The FAA and Eurocontrol are both exploring AI for conflict detection and resolution.

3.2.14 Prototype AI-powered decision-making support systems are already being tested globally. Operational use in UK air traffic management is expected by 2030 with increasingly autonomous capabilities available by 2040.

Trajectory-Based Operations (TBO)

3.2.15 TBO enables aircraft to leverage real-time data and satellite navigation to follow precise, optimised flight paths using 4D trajectories (latitude, longitude, altitude, and time). TBO enables more efficient ATC for precise flight planning and execution. Aircraft will communicate detailed flight plans to air traffic management systems, allowing for dynamic adjustments to optimize routes, reduce delays, and conserve fuel. Initial deployment is underway, with elements of TBO being rolled out as part of SESAR (Single European Sky ATM Research). Full integration is projected between 2027-2035, depending on airspace harmonisation progress with full global implementation expected by 2035[63].

61 Space-Based Augmentation System.

62 The UK's SBAS alternative is not yet operational as of 2025.

63 ICAO International Civil Aviation Organisation set up under the Chicago Convention in 1944.

Future Architecture

3.2.16 If we look at what a combination of these technologies might have the potential to deliver over the next 20 years, the airspace architecture and supporting operations may look like Figure 14 below.

Figure 14: A Vision for Future Airspace Architecture in 2045 (SESAR)[64]

Source: courtesy of and © SESAR Joint Undertaking'

3.2.17 In the even longer term (2050 and beyond) there will be aspirations to introduce:

- Independent flight facilitated by enhanced cockpit-based navigation,
- the automation of ATC – i.e. doing more with the same number of Air Traffic Controllers and
- gate-to-gate operations, whereby an aircraft does not push back from the stand at the start of its journey unless it is cleared all the way through to the destination airport via en-route wayleaves, with aircraft performance continuously monitored against schedule by quantum computers and AI.

3.2.18 The introduction of each of these elements is important, but also dependent upon the comprehensive roll-out of the other technologies in the field that have been highlighted. TBO and the geographical positioning technologies together offer significant scope to ensure air navigation is more accurate, which will help tackle two key policy objectives:

- Amelioration of congestion, because aircraft will be able to use multiple departure tracks and fly more closely together; and
- reduced noise impact and emissions, due to more efficient routings.

64 SESAR: European ATM Master Plan (2020).

3.2.19 Over the next quarter-century, these cutting-edge technologies could fundamentally reshape aviation. They will enhance safety, operational efficiency, capacity and environmental sustainability – a potential contribution to de-carbonisation of the sector of between 4-10%[65] by 2050, while also reducing workloads for air traffic controllers, delays and therefore costs for airlines and passengers. Stakeholders must invest in research, collaboration, and infrastructure upgrades to ensure timely adoption of these innovations. However, securing this promise is dependent on overcoming key political obstacles, like the national geography of airspace and the need for systems to work seamlessly across such boundaries.

B2: Customer Facing Technologies

3.2.20 Generic enabling technologies, particularly automation and AI, are already operational in other capacities at airports. These include baggage and freight handling systems, aircraft handling on aprons and runway thresholds, and adjustment of stand occupancy where weather conditions or other factors disrupt planned schedules. The potential for expanding the use of this technology to improve these sorts of operational and customer facing functions is significant.

3.2.21 Investment in automation and AI will be primarily commercially driven, but governments and regulatory authorities play a crucial role in creating policy and regulatory frameworks that incentivise investment. Encouraging competition and raising expected service standards for customers are important aspects of policy that governments and regulatory bodies need to focus on.

3.2.22 Technologies offering direct benefits in terms of delivering seamless travel and optimising the customer experience include:

- Biometrics
- Blockchain
- Virtual reality and robotics
- Mobility as a service (MaaS)
- Freight digitalisation and automation

Delivering Seamless Travel for Passengers

3.2.23 It's widely acknowledged that while new technologies bring security benefits, they must also provide tangible passenger benefits to gain acceptance and continual review of privacy and public acceptability is essential. The two technologies most in use to ensure a smooth and seamless journey are biometrics and blockchain.

65 In this range 4% reflects Sustainable Aviation estimates of carbon reductions from improved airspace and aircraft operations (see Figure 6), whilst 10% is from easyJet research published in September 2024: https://mediacentre.easyjet.com/blog-posts/view/3949/easyjet-study-reveals-airspace-modernisation-could-save-18-million-tonnes-of-co2-a-year-from-european-aviation.

Biometrics

3.2.24 Biometrics such as facial recognition, fingerprint scanning and iris recognition are increasingly being deployed at airports to enhance security, improve efficiency, and provide a seamless passenger experience. Primary uses include verifying a passenger's identity against their travel documents. This is typically employed at check-in, security checkpoints and immigration control. However, in some places it is also being used at boarding gates and in the TSA PreCheck in the U.S. and at e-Gates in Europe to expedite processing of pre-vetted passengers.

3.2.25 Biometrics offer a more reliable method of verifying identities compared to traditional document checks. Cross-referencing with law enforcement and security databases helps mitigate risks. Automating identity verification speeds up processes at potential bottlenecks such as check-in, boarding, and security screening, thereby reducing wait times. It also eliminates the need for multiple document checks, allowing passengers to move through the airport with minimal stops and creating a more seamless travel experience.

3.2.26 As biometric technology continues to evolve it will continue to seek the optimum balance between security, efficiency, and privacy concerns. Efforts are being made to ensure compliance with data protection regulations to address passengers' privacy.

Blockchain

3.2.27 Airports are complex commercial and operational environments requiring vast amounts of data to be accessible quickly across shared platforms. Blockchain is a technology that enables the sharing of information to take place securely, with all transactions (i.e. uses of the database) being recorded in an account book called a ledger. The power to update a blockchain is distributed between the nodes, or participants, of a public or private computer network. This is known as distributed ledger technology (DLT). The following are some examples of how the technology is currently being used and will be in the future.

Passenger Identity Verification

3.2.28 Blockchain can securely store and verify passenger identities using decentralized and tamper-proof records. This allows for faster and more secure check-in and boarding processes, elimination of repeated identity checks across touchpoints (check-in, security, boarding) and integration with biometric systems for seamless travel.

Baggage Tracking and Management

3.2.29 A shared blockchain ledger can track luggage throughout the journey, from check-in to arrival at the destination. The benefits are real-time updates and reduced incidents of lost luggage, transparency for passengers to monitor their baggage's location and easier resolution of claims or disputes.

Secure Payments, Transactions and Loyalty/Rewards Programmes

3.2.30 Blockchain-based smart contracts and digital payments can streamline financial interactions within the airport ecosystem. They can also unify and manage loyalty programmes across airlines, retail stores, and service providers in the airport. This allows settlements between airlines, vendors, and ground handlers to be automated, reducing fraud and transaction fees, simplifying tracking and redemption of points, and creating interoperable rewards programmes across multiple airlines and partners. All of these innovations aim to increase customer satisfaction and retention.

Cargo and Freight Management

3.2.31 In this environment, Blockchain can provide an immutable record of cargo shipments and documentation, resulting in improved tracking of cargo movements, faster customs clearance through transparent and verified documentation, and reduction in paperwork and associated delays.

3.2.32 Hence the common theme is that blockchain leads to increased efficiency in terms of wait times and operational costs, transparency amongst stakeholders, security in the form of immutable records that prevent data breaches and fraud and scalability allowing easy adaption to increasing passenger and cargo volumes.

3.2.33 By adopting blockchain in these areas, airports can create a more efficient, secure, and customer-friendly experience while reducing costs and operational challenges. In the aviation industry, the vision of an internationally harmonized security system, where passengers and baggage transferring between airports don't require rescreening, is highly appealing. Achieving this vision hinges on establishing trust between screening authorities across different countries and airports, but blockchain technology offers a promising solution for doing so offering a more seamless experience for travellers.

Optimising the Customer Experience

3.2.34 The technologies that can contribute an enhanced dynamic use experience for passengers and freight operators at airports are virtual reality, robotics and MaaS. We consider each of these and what they can deliver below.

Virtual Reality and Robotics

3.2.35 A number of leading airports already use transponder-based systems to offer passengers virtuality reality mapping on their phones to guide them around the airport/terminal they are in, with interactive features such as wait times at security, ordering ahead from shops and food outlets and directions/walk times to gates. A number of others are also experimenting with robots as an interface and information systems for passengers[66], for cleaning and maintenance, and for security and surveillance. The result is that robotics and virtual reality (VR) technologies are increasingly being integrated into airport design and operations to enhance efficiency, security and passenger experience.

66 Halifax, Munich, Kobe and Heathrow have all undertaken trials.

3.2.36 UK airports at the forefront of implementing these technologies include:

- **Heathrow Airport** – employed disinfection robots that use ultraviolet (UV-C) light to sanitize high-touch areas, enhancing hygiene measures.
- **Glasgow Airport** – collaborated with the Connected Places Catapult to trial AI and augmented reality technologies aimed at supporting passengers requiring additional assistance.
- **Belfast International Airport** – tested service robots in the Sip & Stone Restaurant and Bar to enhance both staff and customer experiences.

3.2.37 The integration of robotics and VR technologies in UK airports is expected to increase over the next decade. According to industry analyses, by 2030, technologies such as AI, robotics, and augmented reality are anticipated to be integral to airport operations, enhancing efficiency and passenger experience. However, the exact timeline for these technologies to become commonplace across all UK airports will depend on factors such as investment levels, regulatory approvals, and technological advances. Larger airports with more resources may adopt these technologies sooner, while smaller regional airports might follow as the technologies become more cost-effective and their benefits more evident.

Mobility as a Service (MaaS) Concepts

3.2.38 This is an important transportation concept that combines various modes of transport, such as public transit, ridesharing, bike-sharing, and car rental, into a unified digital platform. It enables passengers to get real-time information on public and private transport options and then plan, book, and pay for their entire journey through a single App or platform, updating dynamically if circumstances change.

3.2.39 MaaS aims to provide a seamless and personalised transportation experience, by offering convenience, flexibility, and cost-efficiency through better travel information that helps people choose the best way to travel. Transportation companies such as Uber, Lyft, ZipCar, and Lime operate one or more MaaS services.

3.2.40 By integrating different transportation options and promoting multimodal travel, MaaS has the potential to improve non-car access to airports, reduce congestion, lower emissions, and enhance overall ground transportation sustainability associated with an airport, while meeting the evolving needs and preferences of travellers.

Freight Digitalisation and Automation

3.2.41 The UK's air freight sector is actively embracing digitalization, automation and robotics in order to enhance efficiency and traceability. Key initiatives and developments include:

- **IAG Cargo:** As a major player in the air freight industry in the UK through its bellyhold operations at Heathrow, IAG Cargo has been investing in digitalization and automation to enhance its operations and try to deal with some of the capacity constraints they face. Their efforts include the development of sophisticated facilities and the integration of advanced technologies to improve efficiency and service quality.

- **Automated Cargo Handling Systems:** The integration of robotics and automated systems is streamlining cargo operations, reducing human error, and improving productivity. These technologies facilitate efficient loading, unloading, and tracking of shipments.
- **Inteliports Limited:** Specializing in intelligent drones and drone ports, Inteliports aims to revolutionise aerial deliveries by creating intermodal hubs for secure drone landings and automated parcel management. Their collaboration with Vodafone underscores the industry's commitment to innovation.

3.2.42 The UK government is actively supporting these advances through funding and policy initiatives such as the Freight Innovation Fund, a £7 million initiative designed to enhance freight sector efficiency by promoting technologies like AI, automation, and sustainable solutions. The aim is to capture a number of key benefits of new technologies. These include:

- **Improved Traceability:** Digital tools provide real-time tracking and monitoring of shipments, ensuring transparency and security throughout the supply chain.
- **Enhanced Efficiency:** Automation reduces manual labour and accelerates processing times, leading to faster deliveries and improved customer satisfaction.
- **Cost Reduction:** Streamlined operations and reduced errors lower operational costs, benefiting both service providers and customers.

3.2.43 And while significant strides have been made towards achieving these goals, the full-scale implementation of these technologies is ongoing, with the industry currently moving towards a hybrid model that combines digital tools with traditional processes. This will require further integration between new digital systems and existing legacy processes, upskilling the workforce to effectively operate and manage advanced technologies, while developing industry-wide standards for digital tools and platforms – all of which is essential for interoperability and widespread adoption.

Summary

3.2.44 Just as the major challenges for SAF are no longer primarily technological, but instead revolve around supply, cost, logistics etc, the main challenges ahead are less about the availability of necessary technologies and more about the political hurdles, such-as cross-border agreements, the planning and implementation of upgraded systems, and ensuring the steady supply of key specialist staff.

3.2.45 Airspace modernisation was a top priority for both the previous government and the new Labour administration. The structure of the UK's airspace today is not dissimilar to what it was 50 years ago and needs to be updated. This is not just about new airspace structures or ATC procedures, it is also heavily about the services that new technologies will facilitate, and ensuring those services deliver value to all airspace users.

3.2.46 In Europe, EASA, through its SESAR programme, and in North America the FAA[67] and NavCanada[68], are embarking on similar technologically driven programmes, with the same aims as CAA, ACOG[69] and prospectively the new Single Design Entity[70] – relating to safety, conspicuity, reduced delays and greater reliability. In each case it is new technologies such as Advanced AI, new satellite navigation systems and trajectory-based operations which will be at the heart of delivering these improvements.

3.2.47 The UK's air freight sector is also on a transformative path towards enhanced efficiency and traceability through digitalisation and automation. With continued collaboration between industry leaders and government support, the sector is poised to achieve significant advances in the coming years.

3.3 Group C: Realising the Potential of New Modalities

C1: Drones and Advanced Air Mobility

3.3.1 Not all the strategic challenges facing the aviation sector are driven by the industry's need to respond to a looming problem, threatening its social licence to operate and grow. The challenges can also be positive, as in the case of drones and other new forms of low carbon modality, where the focus is on how to make optimum use of emerging technology to enhance mobility and utility for a range of public and commercial uses.

3.3.2 Definitional clarity (see Table 3) is the key to understanding the scope and potential of AAM, why it is potentially such a transformational technology, and where, when, and how governments and other stakeholders can intervene to encourage its use for positive public and commercial purposes. This includes the development of new use cases, private sector investment in the new technologies and enabling infrastructure, and the implementation of smart, performance-based regulation that maintains safety standards, minimises environmental intrusion, and in so doing retains its social license to fly and grow.

67 Federal Aviation Administration.

68 Nav Canada: Not-for-profit corporation responsible for Canada's civil air navigation system.

69 ACOG: Airspace Change Organising Group (ACOG) as a UK body that has been coordinating airspace redesign efforts to modernize UK airspace.

70 The SDE, now known as the UK Airspace Design Service (UKADS), is the proposed new body in the UK responsible for the modernised design of its airspace.

Table 3: Advanced Air Mobility Definitions[71]

New and novel ways of transporting people, goods and services by air commercially

Aircraft or aviation systems with significant modifications to their design and operation

Business Models and operational solutions that result in new forms of air-travel and transportation

Novelty derived from the use of advanced technology-driven systems

Term	Definition
AAM (Advanced Air Mobility)	"Air transport services for people and/or cargo between places (…) Local, regional intraregional, urban – using revolutionary new aircraft".
STOL (Short Take-off & Landing)	Conventional aircraft design, with Jet A1/ SAF or prospectively hybrid-electric powertrain capable of operating from runways of less than 1,000m). Used for bush, military and regional flying, the latter where airport infrastructure is limited in scale.
VTOL (Vertical Take-off & Landing)	A VTOL vehicle, or aircraft, can hover, take off and land vertically. This includes traditional rotorcraft, drones used for commercial (i.e. logistical, or surveying tasks) and powered-lift systems – including jet configurations.
cVTOL (Conventional Vertical Take-off & Landing	Combines rotary and fixed wing features in the form of rotors or engines with vertical tilt capability, powered from conventional, hybrid or hybrid-electric fuel sources and used so far mainly for military of offshore missions.
eVTOL (Electrically powered Vertical Take-off & Landing)	A major subset of VTOL often used interchangeably … the "e" referring to electric engine used for propulsion, driven by a battery, fuel cell or 'hybrid' (combined of electric/conventional fuel or battery/fuel cell) power sources.
Urban Air Mobility (UAM)	Air transportation service(s) for people and/or goods ('cargo') in a city, suburban or other form of urban environment(s).
Regional Air Mobility (RAM)	Air transportation service(s) for people and/or goods ('cargo') between cities, across sub-regional/regional and within mega/ multi-regional boundaries or in the context of remote, peripheral, cross-water or countryside environment(s) serving 'rural' markets.
Droneport/Vertiport	Ground-based site or elevated platform developed for drones and eVTOL aircraft to land and take-off, power-up and park.
Use Case	A proposed operation or single set of operations outlining its goals and operating environment. An illustrative example of an AAM concept.

3.3.3 There are three principal types of AAM: drones (non-passenger vehicles, usually for monitoring or freight movements), Urban Air Mobility (UAM – passenger vehicles into and across urban areas), and Regional Air Mobility (RAM – passenger vehicles up to 200-mile distance, 9-19 seat). The latter include small electric planes discussed above in Section 3.1.

71 Source: Northpoint Aviation Services drawing on documents and presentations for Innovate, UKRI and sources.

3.3.4 Table 3 summarises key definitions that cover the many forms AAM can take, while Table 4 below sets out some of their operational and commercial features.

Table 4: Summary of Differences between AAM Modalities

Feature	STOL	CVTOL	eVTOL
Design	Optimized for short runways, high-lift wings	Tiltrotors or vertical and horizontal thrust	Lightweight, electric-focused
Power source	Fossil fuel, SAF, hybrid	Turboprop, SAF, hybrid	Fully electric or hybrid
Use Cases	Remote, regional	Military, offshore	Urban air mobility
Speed	Moderate (200-500 km/h)	Moderate (300-500 km/h)	Low to moderate (100-300 km/h)
Sector Length	Short to Medium	Medium	Short

Source: Northpoint Aviation

Drones

3.3.5 Drone technology is probably the most advanced of the principal AAM groupings[72], with the basic rotary and fixed wing drone designs well established and certified; this has led to a growing sector, used in an increasing range of civilian applications, for example:

- building and infrastructure surveys, e.g. allowing the creation of digital 'twins';
- as a flexible form of logistics serving remote/cross-water locations that are difficult to access by surface modes and specialist packages needing rapid delivery in congested urban environments (e.g. medical supplies)
- a range of specialist missions (e.g. emergency services/blue light use, traffic/resource management, environmental surveys/photography)
- trials for Beyond Visual Line of Sight operations[73] moving mail, e-commerce/retail and smaller general freight.

3.3.6 The summary graphic from Ajuno (Figure 15), which is from the BEIS and DfT Drone Ambition Statement is helpful in giving an overview of user cases where drones can capture value. Following this, Table 5 references a number of commercial trials where drone operations are being used to deliver parcels in the UK and Ireland.

72 RAM (Regional Air Mobility) and UAM (Urban Air Mobility) being the others.

73 Drones are currently licensed to be flown at a range where they stay within the physical vision of the operator; special approvals are required for drone operations that are likely to extend beyond the line of sight of the operator.

Figure 15: Drone User Cases[74]

Source: ajuno

Table 5: Examples of BVLOS Drone Delivery Trials (in 2025)

Trial Name	Operator	Location	Description
Amazon Prime Air	Amazon	Darlington, County Durham, England	Amazon is seeking permission from the Civil Aviation Authority (CAA) to launch drones from its warehouse in Darlington for package deliveries to homes within a 7.5-mile radius. The battery-powered drones can carry packages up to 2.3 kg.
Orkney I-Port	Royal Mail and Skyports Drone Services	Orkney Islands, Scotland	Royal Mail and Skyports have launched a daily inter-island mail distribution service using drones between three islands on Orkney. This project aims to improve delivery times and reliability in remote areas.
FedEx and Future Mobility Campus Ireland Trial	FedEx Express and Future Mobility Campus Ireland (FMCI) Air	Shannon to Foynes Port, Ireland	In October 2021, FedEx, in collaboration with FMCI Air, completed its first scheduled drone last-mile delivery flight in Ireland, transporting goods from Shannon Airport to Foynes Port.
CAA BVLOS Trials	Various Operators	United Kingdom	The UK's Civil Aviation Authority has selected six projects to trial the use of drones flying beyond visual line of sight (BVLOS) for various applications, including consumer deliveries, infrastructure inspections, and emergency services. Amazon's Prime Air is among the selected projects.
NHS Air Bridge	Apian	London	A longstanding trial to provide a logistical air bridge between Guy's and St Thomas' Hospitals in the centre of London has demonstrated success in one of the first operations of its type in the UK. The trials have provided the NHS, the operator and the CAA with valuable data to inform future policy and regulation.

Source: Northpoint Aviation

74 BEIS, DFT: Advancing Airborne Autonomy (2022).

3.3.7 Drones have already established their public service credentials in operations fulfilling a range of use cases, such as infrastructure surveying and medical deliveries to remote areas. However, there is arguably much more that can be done to expand their role and impact. In the short to medium term, the roll out of drone services on a regional level may offer remote and rural areas greatly enhanced accessibility, particularly for freight. It is far less clear that the case for last mile retail home delivery by drone will be accepted publicly as trial schemes in Dublin, Australia and the USA lost public support for this kind of operation the longer and more intensively it was rolled out[75].

Regional Air Mobility

3.3.8 Regional Air Mobility (RAM) is a concept that seeks to bring increased mobility for shorter journeys (roughly less than 250 miles), where the road network is either poor or congested and rail connection are either difficult or non-existent. Typically, these might involve connections which will save significant time:

- to gateway airports or between secondary or tertiary cities (e.g. Plymouth to Cardiff, Dundee to Edinburgh)
- across water (estuaries or islands) or into remote areas,
- on orbital journeys around or across heavily urbanised environments, and
- for cross-country routes between UK regions.

3.3.9 Functionally, RAM will provide this kind of short sector journey using either:

- STOL capable battery or hydrogen fuel cell electric aircraft with 9-19 seats able to access smaller commercial and GA airfields, or
- on thicker routes between small and mid-size urban centres, +30 seat C-VTOL aircraft powered by SAF or hybrid-electric powertrains able to operate without restrictions from runways typically found at smaller regional airports.

3.3.10 This will potentially increase the number of airports from which commercial and privately chartered air services can be provided across the UK, bringing air travel closer to centres of demand or facilitating improved access in more remote areas, providing the airports with new revenue streams and bringing additional jobs and economic opportunities to the local communities they serve.

3.3.11 It will also enable a more responsive air service, allowing regional demand to be serviced closer to its local origins and removing the need for long surface journeys to larger airports, and a more dynamic schedule with greater frequency and network coverage than the operational economics of current forms of regional aviation allow. Finally, it should enable a much more sustainable form of intra and inter-regional air access which will allow it to compete in terms of flexibility, cost and environmental emissions (carbon and noise) with surface transport using fixed road and rail infrastructure.

75 This was for a number of reasons that relate mainly to safety (failing equipment or packages), concerns about privacy, perception of noise which tends to be higher when the source is visible. Reports that Manna's Drone Delivery trial in Dublin faced escalating public opposition since its scale expanded in early 2025; similarly, Google Wing's operations in Canberra between in 2019-24, and Amazon Prime Air's trials in College Station, Texas (starting 2022).

3.3.12 With the exception possibly of China, the most advanced example of this type of aircraft being deployed is in New Zealand where the national airline has acquired 4 Alia CX300 battery-electric e-CTOL[76] aircraft from Beta Technologies used as cargo aircraft flying between Hamilton, Wellington and Blenheim in partnership with New Zealand Post. ZeroAvia have also been undertaking trials using a 9-seat Islander converted to take hybrid electric/hydrogen fuel cell powerplants at Cranfield and as part of the SATE project in Orkney.

3.3.13 In the USA, a NASA study from 2021 envisages transforming over 5,000 public-use airports in the US, into community hubs offering convenient and sustainable air travel options[77]. By implementing an affordable, efficient, and environmentally friendly aircraft network across these airports, more individuals would choose air travel over cars for mid-distance journeys. In the UK a recent study by EA Maven[78] notes an estimated 1,200 potential General Aviation airports with only about 44 currently involved in scheduled aviation and of these only 25 serve most of the need.

"The local airport you may not have even known existed will soon be a catalyst for change in how you travel. It will be a gateway from your doorstep to the rest of the world. It will be a hub for local, renewable energy. It will make sure that your community has rapid access to convenient commerce options and critical supplies. Best of all, it doesn't rely on miraculous technology or infrastructure advancements – the groundwork is already in place."[79]

Urban Air Mobility Systems

3.3.14 Urban Air Mobility (UAM) is the poster child for most of the marketing associated with AAM but is also recognised as likely to be the longest of the three component markets to become established. This is because finding markets in cities with the size, traffic density and wealth required, or alternatively, with a sufficient paucity of surface access alternatives to allow UAM systems the opportunity to become established, are few and far between. UAM markets are expected to be dominated by new electrically (i.e. battery, fuel cell or hybrid) e-VTOL aircraft which have been slow to secure regulatory certification. This has strained the balance sheets of even some of the better-known start-ups, and Europe's two leading proponents Lillium and Volocopter; both forced into administration, reportedly because of the German state being unwilling to make further investment and apparently healthy order books relying on 'paper' commitments rather than being backed by cash deposits. Volocopter has been saved by Diamond Aviation's Chinese owners, but Lillium has declared bankruptcy. This leaves the USA and Far East leading the way in e-VTOL, with Archer Aviation, Joby Aviation, Kitty Hawk and EHang (China) and Hyundai (South Korea) respectively, although Joby does also have some British credentials.

76 Electric conventional takeoff and landing aircraft.

77 NASA: Regional Air Mobility (April 2021).

78 EA Maven: UK Advanced Air Mobility (AAM) Market Assessment for UKRI (2022); https://www.ukri.org/publications/market-assessment-for-advanced-air-mobility-in-the-uk/.

79 NASA SCAD: Regional Air Mobility (April 2021).

3.3.15 Although market speculation has focused on which routes will be the first to see commercial e-VTOL operations, it is also possible that public sector user cases such as deployment by the military, as air ambulances or as platforms for police air patrols could also provide a strong entry market. But commercial services are likely initially to focus on niche routes, for example: between airports; to replace or supplement existing helicopter services; or as a premium service to replace or supplement limos/taxis to central locations where landing facilities are available. The New York Airports to Manhattan market is a good example of both.

Figure 16: Joby e-VOTL operating in downtown Manhattan[80]

Examples of Planned Urban Air Mobility (UAM) Operations

A new joint venture backed by UK vertiport start-up Skyports Infrastructure and Groupe ADP has been selected to operate the Downtown Manhattan Heliport (DMH) for five years from January 2025 renewable every five years for a maximum of 20 years, paving the way for the launch of air taxi services from U.S. start-ups Archer and Joby in 2026. DMH will be one of the first heliports in the U.S. to be modified to handle Electric Vertical Take-Off and Landing air taxis, which are expected to be paired with existing aviation assets like FBOs at large airports or specialist GA airfields in their early stages of adoption.

Archer plan to fly routes between the facility and Newark Liberty International in partnership with United Airlines, while Joby is planning to operate between DMH and New York's John F. Kennedy International Airport and LaGuardia Airport in partnership with Delta Air Lines. A link to Teterboro also seems likely at some point in the future.

Source: courtesy of Joby Aviation and © Joby Aero, Inc.

80 Ben Goldstein: Downtown Manhattan Heliport to be Operated by Skyports, Groupe ADP – Source: Joby Aviation © Joby Aero, Inc.

3.3.16 In addition to their airport focused plans in New York, Archer and Joby are both planning to launch services in Los Angeles with their operations using fixed based operator facilities at the city's numerous airports; whilst Archer also has plans for Chicago between the downtown vertiport a link and O'Hare International and for services in San Francisco[81].

3.3.17 In the Middle East, the United Arab Emirates seems likely to become the earliest market for Archer and Joby, where both aspire to launch initial passenger services later this year. As in the U.S., Archer initially plans to operate in Abu Dhabi using existing aviation infrastructure, including the emirate's five commercial airports and approximately 50 certified helipads at major destinations, such as the Emirates Palace.

3.3.18 Meanwhile in Dubai, Joby and Skyports have partnered with the Dubai Road and Transport Authority to build a network of four vertiports, including sites at Dubai International Airport (DXB), Dubai Marina, Dubai Downtown and Palm Jumeirah. Construction of the first vertiport at DXB has begun and Skyports expects to have two vertiports up and running in time for Joby's commercial launch in early 2026, and the other two are expected to be finished later next year. Prior to launching commercial services, both Joby and Archer have said they plan to conduct non-revenue market survey flights with passengers onboard.

3.3.19 In the UK, the most likely initial routes are between Heathrow and Gatwick; Heathrow, Farnborough, Biggin Hill and the West End, City or Docklands; and between major event venues and other convenient pick-up points that already accommodate helicopter-based operations within and outside the M25.

3.3.20 For eVTOL shuttles to work as part of a wider public transport mix, they ultimately need to have achieved a low enough operating cost base and be able to offer price points capable of capturing a rate of utilization to justify their use, where it is either difficult for forms of public transport to operate or it would be expensive for them to do so. Otherwise, electric or hybrid-electric air taxi services run the risk of ending up as luxury transport option that is only within reach of the ultra-wealthy.

Lower Airspace UTM (Unmanned Traffic Management)

3.3.21 With the rise of drones and other new forms of air mobility, managing the lower airspace where they operate becomes a significant issue. Mainly, most drones operate below about 400 feet. The technology to enable this is known generically as Unmanned Traffic Management (UTM).

81 Ben Goldstein: How U.S. Airlines Are Preparing to Offer Air Taxi Service – Aviation Week (Dec 2024).

3.3.22 UTM leverages advanced technology to enable the real-time management of drones, so as to ensure safety and security of drone operations and optimise efficiency. Key features include:

- Digital Coordination: UTM systems use automated processes to manage traffic, relying on cloud-based platforms, GPS, and internet connectivity to coordinate drone flights.
- Dynamic Airspace Management: UTM adapts to changing conditions in real-time, allowing for dynamic re-allocation of airspace to accommodate emergencies, weather changes, or priority operations.
- Conflict Avoidance: The system integrates data from various sources, such as surveillance radar and drone operators, to predict and avoid collisions.
- Authorization and Compliance: UTM ensures compliance with regulations by issuing flight authorizations and enforcing restricted zones near sensitive locations like airports or military facilities.
- Integration with Manned Aviation: By interfacing with existing air traffic management (ATM) systems, UTM helps ensure seamless interaction between drones and manned aircraft.

3.3.23 Although other countries have embraced UTM including the USA[82] – the EU under its SESAR framework; Singapore, Japan and South Korea in the Far East and Australia/New Zealand – the UK has been a pioneer in deploying UTM systems, focusing on its integration with existing aviation infrastructure.

3.3.24 Between 2022 and 2025, Innovate UK's Future Flight Challenge (FFC) programme sought to enable collaborative exploration of UTM concepts with the aspiration to unlock Beyond Visual Line of Sight (BVLOS) drone operations across the UK. This provided a unique learning opportunity for the nascent industry, Government, and the CAA to test policy concepts as well as novel safety protocols.

3.3.25 As a generic rule, drone operations near critical infrastructure and urban areas are likely to require enhanced UTM to ensure safety. The Future Flight Challenge and other similar projects in Scotland (Project Caelus[83]) and the Solent (Solent Drones for Medical Deliveries[84]) have focussed attention on the roll out of UTM for commercial operations. Although Altitude Angel was the first provider certified by the CAA to provide a digital approval process for commercial drone operators, it is unlikely they will be the last as other suppliers bring UTM services to the UK market.

3.3.26 In the UAE, for example, a project is underway to define aerial corridors and regulations for drones flying BVLOS before the end of 2026. Corridors and regulations are being created via a partnership between the UAE's General Civil Aviation Authority and the country's Advanced Technology Research Council government funded research institutes. The partnership also aims to engineer airspace management systems. There would be no reason why overseas providers such as these could not put themselves forward for certification in the UK.

82 The FAA's LAANC (Low Altitude Authorization and Notification Capability) allows drone operators to obtain automated airspace authorizations for controlled airspace.

83 https://www.gov.uk/government/news/medical-drone-delivery-trials-revolutionising-the-skies-in-scotland.

84 https://solent-transport.com/ftz/drones/.

3.3.27 For those airports, droneports or strips which aren't connected to a digital platform and are still using analogue processes, the future intention is that private providers will offer a service which facilitates the request on behalf of the operator by issuing the relevant airport a detailed summary of the planned UAS operation, via email, to ensure compliance with Article 94A of the Air Navigation Order 2016 so further co-ordination and approval can occur. The aim will be to provide the drone operator with an efficient standardised process at any airport or droneport from which they want to operate, whereas today each airport can be different and subject to complications associated with local bylaws.

3.3.28 Although there are one or two pathfinder companies who are active in this field in the UK, offering UTM services will become a growing competitive market and the UK CAA is supporting its development through regulatory frameworks, sandbox trials and with industry for certification of other service providers, to unlock "true" traffic management capabilities. Scalable UTM solutions are expected to roll out from 2025, with full integration likely by 2035.

Figure 17: Drones being more interactively used on large construction projects

Source: Shutterstock via CAA license

3.3.29 A possible vision of the future is being developed in Norway where Thales and Avinor have formed a partnership to introduce Thales' Topsky – UAS powered by Astra UTM as Norway's nationwide Unmanned Traffic Management (UTM) system. The UTM provides a scalable digital platform for automated UTM and future AAM, helping to manage air traffic and offering compliance monitoring, authorisation management, real-time decision-making, continuous airspace surveillance, automated conflict resolution, and rapid response to dynamic conditions. By implementing a nationwide system, Norway will have access to real-time data sharing, automated airspace access, and enhanced situational awareness for all operators across the country's airspace, including both civilian and governmental stakeholders.

United Kingdom's Contributions to AAM

3.3.30 Although it may not host one of the leading industry OEMs for e-VTOL, the UK does still have several companies actively contributing to the development of AAM technologies. Examples include:

- Vertical Aerospace: Based in Bristol, it specialises in the development of eVTOL aircraft, focusing on creating zero-emissions, fully electric aircraft for passenger transportation.
- Hybrid Air Vehicles: Specialising in hybrid airships, this offers unique capabilities for cargo transportation, surveillance, and remote operations, though not strictly within the AAM category.
- Skyports: This focuses on developing vertiports and infrastructure for AAM operations, creating a network of landing pads and charging stations to support air taxis and urban air mobility services.
- Urban-Air Port: This company develops modular, eco-friendly infrastructure for AAM operations, focusing on creating compact vertiports and charging stations for urban areas.

3.3.31 Additionally, UK-based institutions play a vital role in AAM research and development, contributing expertise in aerospace engineering and collaborating with industry partners to advance AAM technologies. Several leading UK universities are also actively involved in aerospace research furthering the progress of AAM initiatives; these include the University of Warwick, University of Cambridge, Imperial College London, University of Manchester, University of Southampton, University of Surrey, University of Bristol and Cranfield University. In addition to technological advances, significant social research efforts are underway at Birmingham University[85] in tandem with the Flight Challenge initiatives.

C2: Satellite Launch and Support Platforms

3.3.32 Several private-sector space programs and launch vehicles are operating from Western countries under the oversight of NASA, European Union Aviation Safety Agency, Japan and the UK Space Agency, to deliver satellites – for which there is significant demand – into near-earth orbital trajectories. There are also well-funded state programmes in China, Russia and India. However, while the mainstream media, especially in the UK where the launch sector is still in its infancy, focuses on passenger low-orbit space flight and the satellite payload delivery, informed industry speculation is increasingly concerned with the commercial potential of related activities such as manufacturing in zero-gravity conditions, in-orbit satellite maintenance and, ultimately, decommissioning.

85 University of Birmingham: Future Flight Social Insight social science research programme (2022-25); https://futureflightsocial.ac.uk/overview/.

3.3.33 These technologies are still some way from realising their full commercial potential. However, the low Earth orbit (LEO) satellite market, driven by advances in technology and increasing demand for satellite-based services, is particularly dynamic with the market expected to grow from US$ 5.43 billion in 2024 to US$ 25.66 billion by 2032, a CAGR[86] of 21.4%, whereas the wider global satellite market has a CAGR of only 12.3%[87].

3.3.34 The satellite market is dominated by several players[88], notably:

- Airbus SE.
- China Aerospace Science and Technology Corporation. (CASC)
- Lockheed Martin Corporation.
- Space Exploration Technologies Corp. (SpaceX)
- Thales.

3.3.35 These companies are at the forefront of satellite manufacturing, launch services, and related technologies.

3.3.36 In 2024, the UK space sector comprised 1765 companies[89], generating £18.9 billion annually for the economy and attracted more private investment than any country outside the US since 2015. Its strategic aim is to expand its presence in the global space market to 10% by 2030 and in parallel to gain 25% of the global IOSM (In-Orbit Servicing and Manufacturing) market, estimated to be worth almost £11 billion[90]. The UK is leveraging its innovative capabilities, investment efficiency, and government support to establish a strong foothold in this dynamic sector.

3.3.37 However, it is important to note that, as this nascent sector expands in the UK, a modern and flexible regulatory framework is in place to facilitate spaceflight activities. Three spaceports already have operational licences[91], and companies like Open Cosmos, Orbex, and Skyrora are making strides in satellite development.

3.3.38 The sector still faces significant obstacles which could prevent its full potential being realised. These include difficulties in raising external capital, high risks in commercial launches, and government funding allocation issues, all of which have slowed progress.

86 CAGR: Cumulative Average Growth Rate.

87 MarketsandMarkets: Satellites market size and growth (Nov 2024).

88 Mordor Intelligence: LEO Satellite Market Size – Industry Report on Growth Trends & Forecasts Analysis (2024-29).

89 The Times: UK space industry struggling to leave the launchpad (Oct 2024).

90 UK Space Agency estimate.

91 Newquay for horizontal launch platforms, and SaxaVord and Sutherland for vertical launches.

Figure 18: Spaceport Cornwall (at Cornwall Airport Newquay) is the UK's first licensed spaceport[92]

Source: Cornwall Airport Newquay

3.3.39 The result is that some of the spaceports have not proceeded as anticipated, and a potential new growth engine identified in the recent Industrial Strategy Green Paper is under threat. This points to the need for government investment and regulation on a similar scale to that which other governments are doing in their space sector. The National Audit Office has criticised the UK Space Agency for insufficient planning, and sector leaders are calling for more coordinated support and strategic funding to ensure sustained growth and competitiveness in the global space economy.

C3: New Supersonic Civilian Aircraft

3.3.40 Speed, like the ability to fly more passengers over greater sector lengths, has always been a focus for innovation in the aviation sector because of its ability to significantly shorten travel times and so disrupt important markets between leading global city pairs. However, the story of Concorde, both in terms of financial costs and environmental impact, in a world where aviation is seeking to become more sustainable, has meant a successor has been a long time in gestation.

3.3.41 Yet recently some mainly US based companies, have shown an interest in developing aircraft that can deliver significant speed advantage and tap into a commercial market where passengers are willing to pay a premium for access to much faster travel. These companies are tackling key issues including sonic boom mitigation, low fuel efficiency, and regulatory compliance, with most aiming for operational aircraft by the late 2020s or early 2030s.

92 Spaceport Cornwall is the UK's only spaceport licenced for horizontal launch platforms for satellites.

3.3.42 The technological solutions they are promoting entail the utilisation of scramjet[93] engines to achieve speeds above Mach 3 and allow access to suborbital trajectories, typically above 70,000 feet, which allow some suppression of sonic boom. Boom have called this "Boomless Cruise" which relies on the phenomenon of Mach cut-off. This involves flying at a high enough altitude and speed where the sonic boom's shockwaves are refracted upwards and away from the ground due to atmospheric conditions, rather than propagating to the surface. Boom Supersonic is at the forefront of this technology and has developed a new manufacturing facility to start building a supersonic jet which will reduce travel times across the Atlantic, across the continental USA, and between London and the Middle East by a half (i.e. to about 3.5 hours).

3.3.43 The so-called 'Son of Concorde', XB-1, made by Boom, completed its third test flight in 2024, just weeks after its second test run. A full prototype reached Mach 1 or supersonic status in January 2025 and can be seen in Figure 19[94]. The experimental aircraft is the centrepiece of Nasa's Quesst mission[95], and Nasa and Lockheed Martin have joined forces on the project, in hopes of bringing back supersonic aircraft.

3.3.44 The technologies are likely to be very niche initially, especially if they continue to rely upon hydrocarbons, but have the potential to gain momentum in the longer term in the event that a hydrogen-based fuel can be found that gives the level of energy intensity that is required. This is also an area of technology development which has been heavily supported, even if indirectly, by government defence programmes in the US, such as NASA and Defence Advanced Research Projects Agency (DARPA). The only realistic approach to this part of the sector for the UK, if it wants to avoid tying up a lot of money and high-quality skills, is to monitor developments and identify a particular niche where UK companies can contribute – especially for example Rolls Royce and its engine technology – at a later date.

Figure 19: Boom Passenger Jet

Source: courtesy of Boom Supersonic

93 A scramjet (or supersonic-combustion ramjet) is a high-speed, air-breathing jet engine that is capable of operating at hypersonic speeds (i.e. above Mach 5), where the airflow remains supersonic throughout the entire engine, including the combustion process. Unlike standard jet engines, a scramjet lacks moving parts like turbines and compressors, instead using the vehicle's high speed to compress incoming air, which is then mixed with fuel and ignited.

94 www.boomsupersonic.com

95 NASA's Quesst mission uses the experimental X-59 aircraft to demonstrate that supersonic flight can be achieved without a loud sonic boom, generating only a quiet "thump" that is less disruptive to people on the ground.

Summary

3.3.45 Developing and introducing new forms of air mobility can open up opportunities for novel types of services, business models, and markets. They can represent new opportunities to meet the mobility needs of specialist niches, such as blue light and other public services, last mile deliveries, on demand access to high profile locations, orbital rather than radial routings, and empowering the UK to operate independently in the crucial satellite segment of the space industry.

3.3.46 But more importantly they also provide an opportunity for the UK to maintain its prominent position and reputation in the most modern forms of aviation and therefore to carve out a place in new global markets which have significant functional and commercial potential.

3.4 Group D: Other Forms of New Aviation Related Technology

3.4.1 While this review primarily focused on emerging technologies that have the potential to help tackle the aviation's three 'priority' challenges, it has also flagged in passing some other areas of emerging innovation that have the potential to materially impact the industry, which were categorised at 'second tier' or Group D technologies, notably:

D1: Cyber Security

D2: Generic Enabling Technologies

D3: Autonomous Operations

D1: Cyber Disruption

3.4.2 With the emergence of strategic long-term threats in the form of state sponsored cyber-attacks from Russia, Iran and China to supplement existing threats from terrorist and loan wolf operations, this threat to the industry is increasing. However, the threat is recognised and is being taken seriously by airlines, airports, air traffic operations and regulators and technological is being actively engaged to counter it.

D2: Generic Digital Technologies

3.4.3 These include a range of advanced computer-based technologies such as AI, machine learning, quantum computing and others such as automation platforms and robotics, which have the potential to transform many aspects of aviation but are not sector specific and are also being developed and applied in other industries.

D3: Autonomous Operations

3.4.4 Defined as remote or pilotless operations, the autonomous technologies are most advanced in segregated public transport modes such as trams and metro systems. Work on modes where interaction with other vehicles is required is being developed for cars and trucks. However, the difficulties being experienced in bringing the technology to bear in those environments, makes it likely that their adoption in a safety critical environment like aviation is probably some way over the horizon.

3.4.5 These technologies are not considered at greater length in the body of this report because, although they are significant, they are either not aviation specific enough (e.g. cyber security and generic enabling technologies) or have a time horizon for introduction that is likely to be outside the scope of this report (i.e. beyond 2050). However, for completeness we have drawn attention to them and for more details please consult Appendix C (available separately online – see p.137).

3.5 Reflections

3.5.1 As the technology landscape painted in this Chapter makes clear, the breadth and scale of innovation activity currently taking place in the aviation sector, and which is in prospect over the next 25 years, is remarkable even by comparison with other innovation waves since the Second World War that brought periods of transformational change in the sector. Unlike those eras, however, as discussed in Chapter 3, the stimulus for the new technologies is no longer just improved and safer navigation, or the ambition to fly further non-stop or respond to strong long-term growth; now it is about addressing the serious threats to the industry's long-term future. This is closely associated with a combination of its own externalities, Black Swan events, the requirement to get a grip on increasing congestion and falling service standards and the need to find ways to open up new markets so that the sector adapts to new urban and regional landscapes and embraces the opportunities new forms of air mobility can offer (see Table 6 below).

Table 6: Aviation Industry Challenges and Opportunities

INDUSTRY CHALLENGES AND THREATS	NEW MARKETS AND OPPORTUNITIES
• Environmental Impacts (CO_2, noise, air quality) threaten to undermine industry's social license, leading to constraints on growth • Increased congestion (resulting in delays and unreliability) and deteriorating service standards • Greater complexity as new forms of aviation come to market and need to be integrating with airspace users safely • External shocks Covid, Wars, Financial Crises, Oil Dependency, producing a debt overhang and higher risk premiums for investment	• Mobility constraints in remote and rural areas, congested in urban centres and for orbital/cross country routings • Increasing need for global navigation, monitoring and surveillance systems • Growth of E-Commerce and need for last-mile delivery systems • Demand for speed, dynamic convenience and personalisation of travel – social and premium mobility • Development of mobility as a service using real-time digital information and ticketing platforms to interface with other modes

Source: Northpoint Aviation

4. The Technology Roadmap – Process, Progress, Impacts and Prospects

4.0 Introduction

4.0.1 This chapter will explore how the new aviation technologies we have outlined can be brought to market at scale, the processes necessary to bring this about and the milestones that are commonly involved. Importantly, it will examine the likely timescales within which the technologies are likely to emerge and mature and thereby identify which of those identified in Chapter 3 are likely to be most significant and deliver their benefits in a timely manner.

4.0.2 The starting point is to explore the stages of the Innovation Roadmap, and how they are reflected in well-known models of the Technology Development Cycle. Aided by the literature review and industry stakeholder engagement, these allow an informed view to be reached about which technologies are:

- progressing well,
- whether their emergence is compatible with the timescales within which the aviation industry needs to find solutions to its key problems, and
- have commercial, regulatory or policy obstacles which may inhibit them from doing so.

Innovation Roadmaps

4.0.3 Although the literature reveals numerous variants, this research has led to the identification of ten recognisable stages through which new technologies, aviation or otherwise, need to navigate across the complex landscape of innovation, financing, regulation, commercialisation and scalability, if their chances of success are to be maximised. It is important to note, however, that although these component steps are common, they don't always follow the same sequence – for instance, scaling-up may still require regulatory approval even when prototypes have been certified. Equally, some stages may be progressed in parallel.

4.0.4 The concept of an Innovation Roadmap emerged from strategic management and innovation disciplines, gaining traction in the late 20th and early 21st centuries as businesses sought structured approaches to manage technological and market uncertainties. It is used as a visual, strategic tool that outlines the steps, timelines, and resources needed to achieve innovation goals and has proven especially useful in industries where innovation cycles are fast and competition is fierce[96].
Table 7 shows the various stages of the Innovation Roadmap.

96 Northpoint synthesis from a range of sources; a good introduction to the subject is provided in:
Phaal, R., Farrukh, C. J. P., & Probert, D. R. (2004); Technology roadmapping - A planning framework for evolution and revolution. *Technological Forecasting and Social Change*, 71(1-2), 5–26.

Table 7 : Stages of the Innovation Roadmap[97]

No.	Stage	Description
i	Identify Industry Challenges	Pinpoint opportunities for disruption in the target industry.
ii	Research and Ideation	Conduct research to gather insights into the industry, market trends, and emerging technologies.
iii	Proof of Concept	Develop a proof of concept to validate the innovation, the a prototype to demonstrate its value and functionality.
iv	Pilot Testing	Collaborate with industry partners/early adopters to conduct pilot testing, then refine using real-world and user insights.
v	Regulatory Compliance	Ensure compliance with relevant regulations and standards is important in a safety driven industry like aviation. Work closely with the relevant authorities (e.g. CAA) using sandbox opportunities) to navigate the certification/ licensing. See reference in Chapter 5.
vi	Market Penetration	Develop a value proposition and marketing strategy to target early adopters and key stakeholders. Build strategic partnerships, establish distribution channels, and create awareness. This is the phase leading players in e-VTOL are currently at while they await regulatory clearances.
vii	Scale Up	After successfully validating a proposed technology the next critical stage is to secure the necessary funding, resources and partnerships to expand operations. This is the stage of the development cycle that SAF manufacturing has currently reached.
viii	Continuous Improvement	Ongoing monitoring of market trends and technological advances elsewhere, combined with user feedback and data-driven insights to drive iteration and improvements. Future of Flight Industry Group Road Map includes monitoring and evaluation within its strategy.
ix	Collaboration & Ecosystem Development	Create a supportive innovation ecosystem to facilitate partnerships and knowledge sharing and accelerate transformation.
x	Anticipate and Adapt to Change	Disruptive innovation brings industry-wide shifts generating a requirement to remain agile and anticipate changes in market dynamics, customer expectations (i.e. adapt and evolve to stay ahead).

Source: Northpoint Aviation – developed from a range of sources

Models of Technology Development Cycle

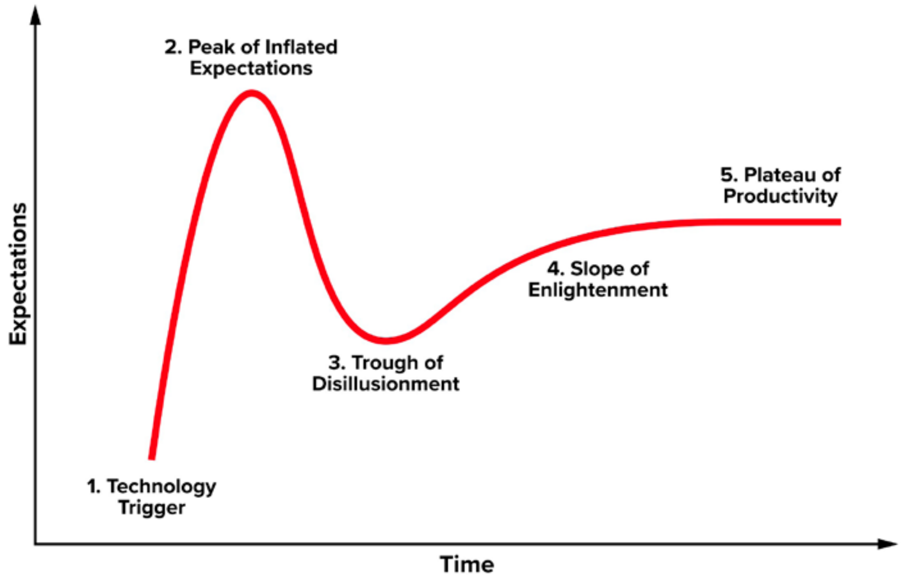
4.0.5 Numerous theoretical models have been developed to understand these component stages, using parameters such as productivity/value against effort/time or expectations against time. Typically, they postulate that once a technology is matured – technically, commercially and in terms of up-scaling – a new or better variant may disrupt the now old technology, causing it to lose market share and ultimately to be retired.

4.0.6 A good example of this pattern can be seen in relation to Sustainable Aviation Fuel (SAF), where original source materials in the form of waste oils, animal fats and solid municipal waste are being overtaken in terms of volume by agricultural residues and energy crops, and in the future possibly algae. However, these in turn are likely to act as a transitional source while the technology required for large scale production of synthetic SAF is optimised, brought on-line and scaled.

97 Adapted from StartSmart CEE's 10-step innovation process, combined with elements from Stage-Gate methodologies.

4.0.7 The different elements of the Innovation Roadmap are also evident in the Technology Hype Cycle graphic, the best known of the technology development models. The variant in Figure 20 below[98] is a more complex representation of what happens along the adoption curve.

Figure 20: Gartner Hype Cycle



Source: Shutterstock via CAA license

4.0.8 The Figure shows the process, wherein new innovation gets talked-up (i.e. hyped) by its proponents (as for example e-VTOL has been over the last 2-3 years), but then the timescales associated with regulatory certification create a requirement for long term financing. This is not normally a feature of venture capital investment and can lead to market failure even for sector leading companies (e.g. Lillium and Volocopter going into administration). However, the curve also suggests that once market expectations about the size and speed of build-up of the e-VTOL market have become more realistic, and consolidation of OEMs and licenses for their aircraft designs have taken place, a market of around 30% of initial theoretical estimates is likely to emerge. This is based on the assumption that half a dozen or fewer OEMs have the quality of product and depth of financing to reach the end of the hype cycle. It also means that in e-VTOL's case, the date at which widespread urban air mobility may become a reality is further off than originally thought.

4.1 Evaluating the Potential Significance of Technologies

4.1.1 As a framework for evaluating the relative significance of each of the different technology groups reviewed, three assessment tables have been developed (see Tables 8-10), each covering one of the priority challenges facing the industry, subdivided into relevant technology groupings. There are then four columns providing a high level summary assessment of the significance of each technology, their prospects for being realised, and a best estimate of the likely timescale for introduction and reaching maturity.

98 The Gartner Hype Cycle also offers useful insights in this regard but focused on explaining the five key stages of the cycle (i.e. innovation triggers, peak inflated expectations, disillusionment, enlightenment and plateau of productivity) and why they occur, rather than how they relate to commercial decision-making in the above figure.

Group A Technologies

4.1.2 Table 8 below highlights **Sustainable Aviation Fuel** as being both fundamentally important – the highest ranking in the assessment scale – in that it is already being used for blending in substantial volumes[99] and in production in several countries. Its prospects are only ranked as 'good' in the table below, even though the technology behind the production of SAF is well understood, because the challenge of finding sufficient sustainable source material and scaling production to where it needs to be and at a price the market will bear, has yet to be overcome.

4.1.3 **Hydrogen** is rated as potentially very important, but its prospects are uncertain as there have yet to be any demonstrably successful public trials at scale of hydrogen being burnt in jet engines. Whilst electric power sources and propulsion systems are notated in the table as positive in terms of prospective realisation but only moderate in terms of impact. This is because of the size of aircraft and networks that will use them will be small and the seat capacity of the aircraft will be limited. In addition, the sector lengths they will be able to fly are short, constraining flights to domestic and near European markets.

Table 8: Assessment of Group A Technologies

Group A Technologies: Making Aviation Environmentally Sustainable			
Aviation Challenge	**Technology**	**Significance**	**Prospects**
A1: Sustainable Fuels*	**Sustainable Aviation Fuel (SAF)**	**Fundamentally Important** Projected to be responsible for 37% of industry Net Zero Co2 Reductions	**Good**. Multiple sources of raw materials. Different refining approaches possible Govt committed and supportive – Jet Zero
	Electric-Powered Aircraft	**Moderate Impact Likely** Potentially important for decarb. of domestic and near EU flying	**Positive.** Trials underway, pre-sales made Several group working on different formats
	Hydrogen or Amonia Powered Aircraft	**Potentially Important** Longer term option; technology for use in jet engines under development	**Uncertain**. Focus for EU; USA also evaluating Airbus leads EU efforts, Boeing supporting US work with power unit manufacturers
A2: Propulsion Systems	**Ultra High Bypass Ratio Turbofans**	Impact likely to be **incremental** only. Improvements are now marginal	**Excellent.** Sales made, and already being rolled out
	Batteries/ Fuel cells	**Small** impact likely; **moderate** in UK. Will only power 9-29 seat aircraft, 600km in short term	**Positive,** and enhancements being sought. Dependent on battery tech; fuel cells/offer alternative; 900km & 50 seat med.term
	Supersonic/ Hypersonic	**Small** in short to medium term More significant if 100 seat jets built	**Promising.** Zoom prototype trialled, full test aircraft being built, production facility acquired
	New engines burning H2/ NH4 directly	**Very large** for short haul flights. Require new airframe. Limited for Long haul/larger aircraft – who will still rely on SAF	**Uncertain.** Concept designs only. Co-ordinating all of the elements needed for a hybrid plane will be challenging
A3: Aircraft Design	**Delta Wing and New Materials**	**Moderate.** Material improvement on predecessor – if combined	**Good**, already a feature of Airbus aircraft
	Canard and High Aspect Wings	**Incremental**	**Possible.** Being trialled, but likely to be used only on short haul aircraft. Net value not clear
	Blended Wing Body (BWB)	Potentially **large**	**Uncertain,** required to support movement to H2. Airlines need to demonstrate commitments

Source: Northpoint Aviation

99 Most of the 8 existing refining pathways are universally accepted.

Group B Technologies

4.1.4 Table 9 below highlights the future significance of enhanced Air Navigation Systems to the industry in tackling congestion and modernising airspace and suggests their prospects for successful introduction are good. By comparison, the impact of passenger facing technologies, although helpful, are likely to be somewhat less consequential, even though their potential for adoption is considered excellent as they are already being rolled out and new variations devised. There is also still some way to go before full scale-up and market saturation is reached.

Table 9: Assessment of Group B Technologies

Group B Technologies: Tackling Congestion, Delays and Inefficiencies			
Aviation Challenge	Technology	Significance	Prospects
B1: Airspace Modernisation*	**Remote Tower & GNSS** **Increased Cockpit Navigation** **P-RNAV** **Gate-Gate**	**Important impact.** Varies by tech type, but significant for reducing delays, safety and potentially 10% carbon savings	**Good**. Strong demand, basic technology exists; needs to be packaged well, then phased in over a long period. Will need legislation and incentives to encourage adoption
B2: Passenger Facing Technologies	**Biometrics** **Virtual Reality platforms** **Robotics** **Surface Access – Decarbonisation/ MaaS**	**Moderate** impact on pax journey by air should make passenger transition through terminal quicker and easier	**Excellent.** Being rolled out; but needs to be at scale. Next generation improvements already being planned.

Source: Northpoint Aviation

Group C Technologies

4.1.5 If we look at the new modality related technology in Table 10, then the launch platforms the UK has been developing for near-earth satellites represent a small but significant new domestic industry, and the satellites put into orbit certainly serve a range of important functions. Conversely, in the case of Advanced Air Mobility (AAM) it is only drone technology which is likely to have reached full maturity and therefore to be seen at scale in the near future.

4.1.6 Industry sentiment, together with detailed demand assessments by EA Maven, suggests that Regional Air Mobility, using fixed wing electric aircraft will be likely to expand more rapidly than the urban air mobility – using e-VTOL concept aircraft. However, neither of them will achieve drone-like levels of activity for a decade or more and the prospects for fully autonomous e-VTOL flights are uncertain and likely to remain so for at least another 15 years – and potentially beyond 2050.

Table 10: Assessment of Group C Technologies

Group C Technologies: Realising the Potential of New Modalities			
Aviation Challenge	**Technology**	**Significance**	**Prospects**
C1: Drones and Advanced Air Mobility*	**Drones** **UTM Sytems** **Manned E-Vtol** **Autonomous E-Vtol**	**Very Important.** Drones are a technology whose full potential has not yet been realised; market for e-VTOL likely others initially smaller, more specialised. Mass use 15 years away.	**Good**. Drone roll out slow but underway – need to broaden user cases and put regulatory frameworks in place. Same for other systems, but 5-10 years behind with slower roll out
C2: Satellite Launch and Hosting	**Nr Earth Satellites** **High Altitude Platforms**	**Moderate**. Has allowed UK to develop an independent space sector; satellites important in many spheres	**Good.** Variety of launch platforms viable, substantial market in which UK can compete
C3: New Supersonic Civilian Aircraft	**Boom Supersonics (Mach 1-3)**	**Limited.** Leading companies are US based; no Concorde legacy. Focus on BusAv market means risks social license; runs counter to global climate politics	**Good**. Two companies have established manufacturing facilities, certification expected by 2026/27

Source: Northpoint Aviation

4.2 Public Attitudes

4.2.1 A crucial dimension of any major technological change programme is how it is perceived by users and the wider public. Given the range of issues and technologies discussed in this report, there is no single source of comprehensive information. However, we have identified several useful sources, of which the independent annual survey data from the NATS Aviation index is particularly insightful. The summary which follows draws heavily on this but also on other sources where appropriate [100]. The following reports for example are also useful resources for attitudinal information:

- GE Aerospace Industry Survey (2023)[101]
- Resources for the Future (RFF) Report – Navigating Sustainable Skies (2024)[102]
- Market Research Reports (e.g., Euromonitor, BIS Research)[103]

100 DfT: Bryce Tech (2023); Avionics International: EASA Releases First Study on Citizens' Acceptance of UAM by Kelsey Reichman (May 2021); Institute of Mechanical Engineers: Public perceptions – Drones Survey results (Dec 2019).

101 Focuses on the technologies that are seen as critical for achieving net-zero emissions by 2050 and the role government should play in supporting sustainable aviation technologies.

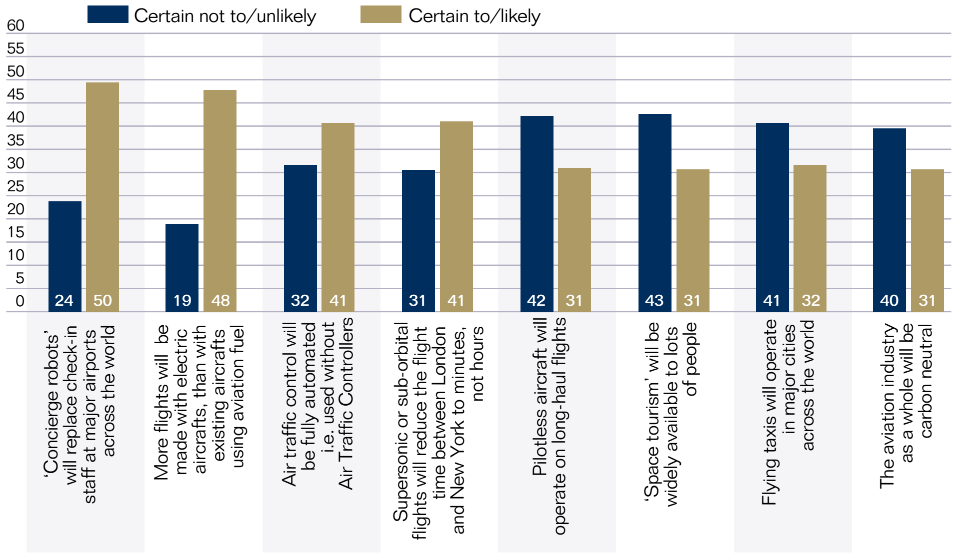
102 This report examines challenges and strategies needed to deliver greener aviation, including a section on consumer behaviour toward new technologies. It emphasizes the need for research into public attitudes and cites consumer behaviour as critical for adoption.

103 Provides industry trend analyses, occasionally including consumer sentiment. For example, Euromonitor's 2022 Global Overview of the Aerospace Industry and BIS Research's aerospace reports touch on public interest in technologies like drones and next-generation aircraft.

Overview of Emerging Aviation Technologies

4.2.2 Between 2021-23 the NATS Aviation Index Survey sought the general public's views on emergent aviation technologies and Figure 21 provides a summary of their outlook on future technologies, demonstrating varying levels of optimism about their potential emergence. The results suggest that whilst technologies with shorter term horizons for roll out, such as robots, electric aircraft, greater automation of ATC and re-introduction of supersonic passenger aircraft, were all greeted expectantly, more futuristic innovations such as pilotless commercial aircraft, e-VTOL base air taxis[104] and comprehensive decarbonisation of the industry were met with greater scepticism.

Figure 21: Likelihood of Technologies Becoming Mainstream by 2050[105]



Source: NATS Aviation Index (2023)

4.2.3 In relation to the first key industry challenge we have identified (i.e. making aviation more sustainable), the most recent NATS survey in 2025 suggests there is a majority view amongst the public that the industry should focus on improving flight punctuality rather than reducing emissions, with some 63 per cent of UK adults indicating that ensuring planes take-off and land on time should be a priority for the sector compared with 56 per cent who said the same for cutting emissions. However, the figure for reducing emissions is up from 53% in 2024, but down from 70% in 2020[106].

104 Likely to begin commercial operations in Dubai and New York in 2026, but later in the decade in the UK.

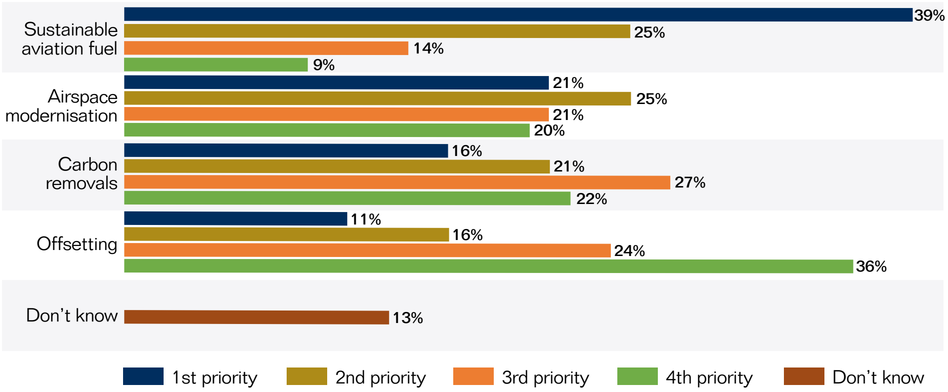
105 NATS: Aviation Index (2023).

106 TravelAir Travel: Flyers say airlines should prioritise planes being on time over reducing emissions (29th July 2025).

4.2.4 When asked to prioritise strategies for reducing aviation emissions, the UK public ranked Sustainable Aviation Fuel (SAF) as the top choice (see Figure 22) – ahead of airspace modernisation, and well above carbon removals and offsetting. This reflects growing recognition of SAF as a practical, scalable alternative to conventional jet fuel.

Figure 22: Prioritisation of Aviation Carbon Reduction Measures

Question: The aviation industry is exploring several options to help reduce the impact of greenhouse gas emissions caused by air travel. Please read the following options and rank them in order of the priority you think the aviation industry should give them to reduce the impact of greenhouse gas emissions caused by air travel.



Source: NATS Aviation Index Survey (2025)

Airspace Modernisation

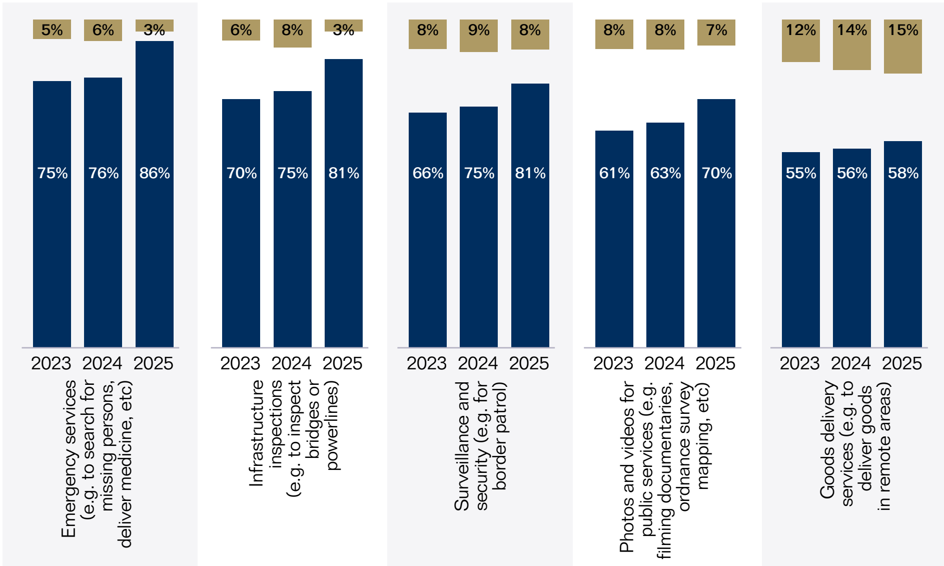
4.2.5 There is also evidence of clear support for addressing a key aspect of our Group B technologies, modernising the UK's airspace. This seems to be associated with its perceived importance for the future of aviation, with 69% of respondents agreeing that airport expansion cannot happen without airspace modernisation, while 67% view airspace reform as an essential part of the UK's broader infrastructure improvement agenda.

Emerging Technologies and the Future of Aviation

4.2.6 The 2025 Aviation Index highlights growing support for next-generation Advanced Air Mobility solutions such as flying taxis and drones. Whilst there is notable support for the use of drones across a range of applications, especially where it involved some sort of public service or safety role, the prospect of using drones for goods delivery services was met with significantly greater scepticism.

Figure 23: Public Support for Different Drone User Cases (2023-25)[107]

Question: To what extent do you support or oppose drones being used for the purpose of...



Source: NATS Aviation Index 2025

4.2.7 As Figure 23 shows, the majority of the public backs their use in a range of practical applications. For example, 86% support drones in emergency services, 81% for infrastructure inspection, 74% for security and surveillance, and 70% for public-sector photography and videography. These results suggest drones are widely perceived as effective tools for improving efficiency, safety, and supporting critical public functions where speed and precision are essential.

4.2.8 However, concerns persist around privacy, airspace safety, and noise pollution and could potentially grow as drone usage expands, particularly in urban or residential areas where their presence is more visible. All of which suggests that public confidence depends heavily on how drones are regulated, where they are used, and the transparency of their purpose.

4.2.9 In relation to other forms of AAM – most notable e-VTOL (when used in the form of flying taxis) – these seem to have caught the public imagination far less, although this could be influenced by the sector's lower visibility and lack of familiarity amongst the public about how the technology could be used. According to the NATS Index survey 40% of the UK public have said they would be open to using them if available – up from 34% in 2024. While enthusiasm is building, concerns persist. The top reservations include safety, cost, a lack of trust in this still-emerging technology, perceived lack of personal need, environmental considerations, and others[108].

4.2.10 These findings were also reflected in the EASA study, which found that:

- 64% of the respondents would be interested in using drone delivery;
- 49% would be interested in using an air taxi;
- 43% would be interested in using both, and that;
- 71% were likely to make use of at least one service.

107 NATS: Aviation Index – Page 21 (2025).

108 NATS: Ibid.

4.2.11 Fundamentally, the study found public interest in the potential use of AAM in the health and safety domains, but far less for private and individual uses, such as sightseeing and the use of drones for delivery purposes. And while the use of drones to deliver heavy cargo over long distances registered 25 percent support, using UAM vehicles to transport passengers garnered the least support from respondents with this form of use case all use cases receiving 10 percent or less support.

4.3 Timelines for the Implementation of New Aviation Technologies

4.3.1 Having considered our significance of the 'focus' technologies, it is important to understand which of them:

- are either making or seem likely to make good progress toward mainstream commercial accessibility in time to make a useful contribution towards addressing the main industry challenges.
- are likely to achieve the relevant timetable milestones (i.e. the 5-year term of a new government, the end date of 2050 and at the halfway point of the decades in between), without the need for much external support.
- will probably struggle to achieve either of the above because of the complexity of co-ordinating the number of actors involved, the difficulty of moving from prototype to industrialisation without significant investment support or question-marks over the long-term viability of the solutions; or
- could have the potential to make significant progress in the event of robust interventions from the UK government, the regulator, regional development agencies and local authorities who are keen to back local innovation or investment in fledgling companies/industries that could, if successful, have a major impact on their economies.

4.3.2 Tables 11-13 contain qualitative assessments of the progress being made in relation to each group of technologies, their significance, and the likely timescales for implementation. So, for example, SAF and new electric and hybrid-electric propulsion system show positive signs of progress, while there remains much greater uncertainty around the practicalities of delivering hydrogen as a power source. The roll out of customer facing technologies is going well, while there is also progress in the UK on airspace modernisation. In terms of new modalities, drone use appears to be picking up speed, while expectations for e-VTOL are being tempered, and the prospects for a new civilian supersonic passenger aircraft look surprisingly positive based on recent Boom trials. However, in addition to these technology specific assessments our investigations also allow us to make some more generic observations.

4.3.3 As we navigated our way through the landscape of innovation in aviation in the UK and beyond in Chapter 3, it became clear that not all the new wave of technologies are proceeding at the same speed, with many being at different stages of development and adoption. It was also notable that certain technologies are likely to serve as early or transitional solutions and thus may not be as prominent in 20-30 years' time whilst others may appear later within this timeline, and others again may well prove more durable and remain significant for a considerable period.

4.3.4 The timescale over which any individual or group of technologies will work its way through the typical stages of the development cycles will vary materially and hence it is hard to predict with any certainty. This report has taken 2050 as its end-date, reflecting for example the significance of that timeline for Net Zero policy targets at a national and international level. However, the progress of some technologies through the development cycle, no matter how well supported, may not achieve the adopted milestone date of 2050. The commercial roll out of new hydrogen-only aircraft and full implementation of some of the more ambitious air traffic management concepts such as gate-to-gate and autonomous passenger flights, are unlikely to reach full-scale adoption until well past this date for commercial, technical integration and social license reasons respectively. Equally, for 'burning platform' issues such as climate change that kind of timeline will be far too long and there will be a need to introduce additional policy to accelerate timescales to meet wider policy imperatives.

4.3.5 Differential progress across the broad spectrum of technologies reflects the fact that some passenger facing technologies are incremental and thus can pass through the development cycle more quickly (i.e. in less than 5 years) and will appear sooner on our roadmap, whereas others are far more complex or have higher risks or cost profiles that may undermine or delay the speed of take-up. So, for example, making meaningful change that modernizes controlled airspace management is typically a long and complex affair, not helped by conflicting state interests and different equipment specifications across airspace boundaries. The introduction of GNSS and technologies facilitating 'continuous descent' and 'precision R-Nav' procedures allowing greater numbers and more accurate design of noise departure routes represent recent wins; remote tower operations are also now gaining traction.

4.3.6 The introduction of equipment enabling universal conspicuity and digital UTM (Unmanned Aircraft System Traffic Management) will offer material benefits to General Aviation as well as new forms of mobility, as lower airspace becomes more crowded with drones and AAM aircraft. Most of the more futuristic airspace modernisation concepts that are needed to deliver step-change performance in air navigation systems and ATM performance are heavily dependent on the data-focused, generic enabling technologies that were identified above. Machine learning and quantum computing are particularly important to increase cockpit-based navigation, reduce controller input and ultimately enable autonomous flight. However, like hydrogen aircraft, it will take a long time to convince safety regulators to approve such innovation and then for it to secure funding for commercial roll out, extending the technology development timeline well beyond 2050.

Table 11: Estimated Timescales and Hurdles to Development for Group A

Group A Technologies: Making Aviation Environmentally Sustainable				
Aviation Challenge	**Technology**	**Timescale for Introduction**	**Timescale to Reach Maturity**	**Outstanding Hurdles to Development**
A1: Sustainable Fuels*	Sustainable Aviation Fuel (SAF)	Now	2025-35	Finding sufficient suitable feedstock(s) and green energy to produce SAF sustainably. Scaling production quickly enough to meet extant demand for future Net Zero targets. Incentivising take-up by keeping the unit cost of SAF competitive with Jet A1. Reducing capital investment risks to levels the private sector will support.
	Electric-Powered Aircraft	2025-35	2030-40	Hybrid, battery or fuel cell powered aircraft all being tested on 9-19 seat with up to 300km range. This offers limited routes – need 30-50 seats and +500km range. New infrastructure and access to adequate supplies of green energy at airports. Finding enough sector lengths that are feasible, implications for fleet size & EV aircraft market.
	Hydrogen or Amonia Powered Aircraft	2030-40	2050+	Energy density NH4 better than H2 and more stable, but H2 is current focus. Need tech flex? Capital required to build productive capacity and make it accessible. Large supply clean energy to make the fuel sustainable. Competition for market share between fuels and from other modes.
A1: Propulsion Systems	Ultra High Bypass Ratio Turbofans	Now	2025-35	Rolls Royce key OEM. Offer further efficiency gains, but incremental not game changing. Roll out across fleet will take time; provides important CO_2 gains while SAF production ramping up.
	Batteries/ Fuel cells	2025-30	2030-40	Access to, and cost of, materials. Batteries/fuel cells of right power and duration crucial. Safety implications of battery failures/fires.
	Supersonic/ Hypersonic	2025-35	2035-45	Scramjet/hypersonic in development; start with business aircraft (e.g. Zoom) before scheduled. Significant environmental implications – noise/CO_2; only small no. markets/routes justify its use.
	New engines burning H2/ NH4 directly	2035+	2050+	Under development US/EU, no commercial prototype trialled yet. No long-haul sectors possible – only short and mid haul, due to fuel volumes required.
A3: Aircraft Design	Delta Wing and New Materials	Now	2025-35	Compatible, new alloys – recyclable & reduce aircraft weight; BLADE will deliver less drag. Already being used in new aircraft already capturing, roll out to majority of fleet will take time.
	Canard and High Aspect Wings	2025-30	2030-40	Materially better CO_2 performance vs existing wings, but not game changing. Suitable mainly short/mid-haul jets; not long haul. Roll out as interim step or await BWB?
	Blended Wing Body (BWB)	2035	2040-60	Airbus lead; reduces CO_2 – development associated with introduction of hydrogen fuel. Conceptual stage. Costs/risks associated with entirely new plane design large. LH possible? Market size for this kind of design – like A380 or B787? Re-skilling + production capacity issues.

Source: Northpoint Aviation

Table 12: Estimated Timescales and Hurdles to Development Group B Technologies

Group B Technologies: Tackling Congestion, Delays and Inefficiencies				
Aviation Challenge	**Technology**	**Timescale for Introduction**	**Timescale to Reach Maturity**	**Outstanding Hurdles to Development**
B1: Airspace Modernisation*	Remote Tower & GNSS	Now	2025-35	Underway but speed of roll out could be faster; costs a potential issue
	Increased Cockpit Navigation	Now	2025-35	Underway, but will take time to roll out because of costs and training
	P-RNAV	Now	2025-40	Underway, complex to introduce, needs cockpit equipment, takes time to secure benefits
	Gate-Gate	2035	2035-50	Progress dependent on other technologies and slow
B2: Passenger Facing Technologies	Biometrics	Now	2025-35	Underway, but expensive for smaller airports to install
	Virtual Reality platforms	Now	2025-35	Underway, but focused on larger airports
	Robotics	2025-30	2030-40	Trials happening but equipment functionality and benefit case not yet clear
	Surface Access – Decarbonisation/ MaaS	2025-30	2030-40	Underway but speed of roll out could be faster; costs a potential issue

Source: Northpoint Aviation

Table 13: Estimated Timescales and Hurdles to Development Group C Technologies

Group C Technologies: Realising the Potential of New Modalities				
Aviation Challenge	**Technology**	**Timescale for Introduction**	**Timescale to Reach Maturity**	**Outstanding Hurdles to Development**
C1: Drones and Advanced Air Mobility*	Drones	Now	2025-35	Regulation and social license holding it back
	UTM Sytems	2025-30	2030-40	Expensive and complicated; providing comprehensive not area coverage, CAA capacity
	Manned E-Vtol	2025-30	2030-40	Expensive, limited markets initially, require new infrastructure
	Authomous E-Vtol	2035	2035-50	Certification process, passenger acceptance
C2: Satellite Launch and Hosting	Nr Earth Satellites	Now	2025-35	Underway – reliability of platforms
	High Altitude Platforms	2025-30	2030-40	Unproven – potentially lower cost and more reliable
C3: New Supersonic Civilian Aircraft	Boom Supersonics (Mach 1-3)	2027	2030-35	Regulatory approval awaited; Business Aviation configuration brings potential for social license issues

Source: Northpoint Aviation

4.3.7 What can be noted in Tables 11-13 is that incremental technologies in A2, B1/B2 and C1/C2 already being introduced, or about to be, with rapid maturity expected to follow, whereas more radical technological departures such as hydrogen propulsion, blended wing body design, gate to gate navigation and passenger forms of AAM taking longer to introduce and then mature.

4.3.8 It is, therefore, essential to recognize a distinction between mature and emergent technologies, as different levels of technological maturity necessitate varying degrees of government and regulatory engagement. A coherent strategy, supported by clear route maps and institutions such as the ATI[109], the Jet Zero Taskforce, and Future of Flight Industry Group, is crucial for effective navigation of overarching government or sectoral missions and subsidiary programmes.

Mature and Emerging Technologies

4.3.9 These technologies:

- have already been brought to market,
- have proven functionality, being established, tested, and certified,
- are recognized for their demonstrable value,
- are either in production or will be rolled out within the next 2-3 years,
- are available at accessible prices, facilitating scaling-up.

4.3.10 Examples of technologies likely to achieve full commercialisation and roll out by 2035 include: hi-bypass turbofan jet engines, passenger and staffing biometrics, automation of baggage and freight systems, P-RNAV, remote towers for ATC, enhanced cyber defences for safety-critical operational equipment, drones, and lower orbit satellite launches.

4.3.11 And while these new technologies are relatively mature, there is still a role for government in setting standards, certification, and regulation to support or facilitate market creation, as seen in recycling, electric cars, and solar panels.

4.3.12 These technologies have completed the innovation stage, and their potential is recognized to the extent that they are being designed and tested for civil aviation purposes, with market introduction expected between 2025 and 2035. However, although technically proven, they frequently face commercial, logistical and other non-technical challenges in moving to general adoption across the industry. Table 14 provides an overview which differentiates between the current mature technologies and the new ones that are emerging.

109 Aerospace Technology Institute.

Table 14: Maturing vs Emerging Technologies

Different Levels of Technological Maturity Require Different Levels of Government and Regulatory Engagement	
Maturing Technologies	**Emerging New Technologies**
These technologies have: • Proven functionality (i.e., are established, tested and certified). • Are recognised as having demonstrable value. • Are in production and being rolled or will be in the next 2-3 years. • Are available at an accessible price driving scaling-up. **Examples include:** • Hi-bypass turbofan jet engines. • Passenger and staffing biometrics. • Automation of baggage and freight systems. • P-RNAV and remote towers for air traffic control. • Automation and robotics in Cargo handling. • Enhanced cyber defences for safety critical ops. • Drones and lower orbit satellite launches. There is still role for Government, through standard setting, certification and regulation	**Innovation stage completed and potential of the technology recognised. Being designed and tested for Civil Aviation purposes – market introduction 2025-2035. Examples:** • Wing design: Laminar flow (Blade), high aspect ratio. • New forms of propulsion: Electrical, hypersonics. • Sustainable Fuels: SAF from waste and bio sources and Hydrogen Fuel Cells. • AAM: E-VTOL and C-VTOL aircraft. • AI, Machine Learning, Quantum Computing. • Air Navigation: GNSS, universal electronic conspicuity, 5G UTM (Aircraft Systems). **Can be accelerated along development curve by:** • Clear regulatory framework. • De-risk product design/testing and scaling-up phases. • Incentivise investment, fiscal market-making. • Route maps to market. Commitment to long term programmes. • Supporting the establishment of production facilities.

Source: Northpoint Aviation

4.3.13 Accelerating these technologies along the development curve can be achieved through clear regulatory and policy frameworks, de-risking product design and testing, incentivising investment through fiscal market-making, identifying route maps to the market and supporting the establishment of production facilities.

4.3.14 Conversely, where technologies are not yet mature, and are still being refined and proven, it is arguable that there is a case for Government to adopt a more hands-on supportive role to enable the technology to transition more quickly through the development cycle. This kind of more pro-active role worked well in relation to 5G (legislation and spectrum auction), vaccines (funding research and speeding-up clinical trials and approvals) and graphene (provision of substantial funding, establishing research hubs, supporting standardization, and fostering industry-academia collaboration).

Future Technologies – Horizon Scanning for Future Innovations

4.3.15 If we look still further ahead, beyond the time horizon adopted for this report (i.e. 2050), it is possible to discern other potentially significant technologies that are currently at the research and concept development stage that have not yet been prototyped or beta-tested. They include:

- Synthetic aviation fuel (SAF) from captured carbon dioxide (CO_2)[110].
- Gate-to-gate routing concepts using cockpit-based Air Navigation Services (ANS) and enabled by quantum computing.
- Direct burn Hydrogen or Ammonia as fuel for jet propulsion systems.
- Blended wing bodies, low drag tailfins and mainframe laminar flow materials.
- Autonomous operation initially of AAM and ultimately civil aircraft.

4.3.16 Given the Government's role in setting long term policy, commissioning applied research (e.g. through UKRI), incentivising venture capital and championing the development of 'smart' regulation, the CAA has been asked to 'horizon scan' such technologies. The aim is to gain a better understanding the implications they could have for UK aviation, whether UK industry and research institutions could play a role in developing them, to impact they could ultimately have on the sector and what programme resources they are likely to require over what timescale?

4.4 Hurdles to the Realisation of New Technologies

4.4.1 Even where the prospects for certification and ultimate commercialisation of the new technologies, examined in Chapter 3, seem positive and their likely impact on the sector's reach, safety, commercial viability or environmental footprint is material, they will nevertheless still face barriers (commercial, operational and policy orientated) that could hold them back. This is where support in the form of government intervention or productive interaction with regulators can be very helpful. Potential issues include:

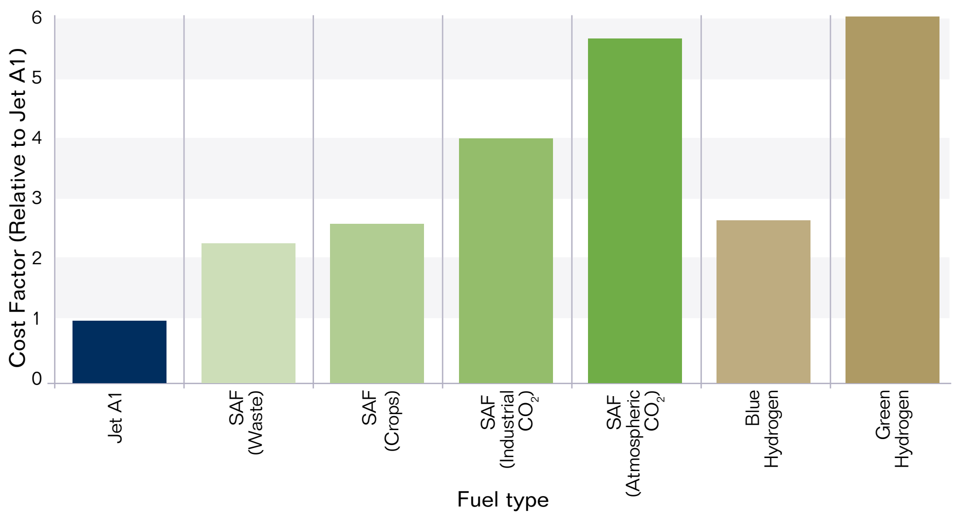
- resource shortages (e.g. sustainable materials and renewable energy from which to generate SAF);
- performance limitations relative to what might ideally be required (e.g. sector length, speed, reliability – battery limitations);
- regulatory timescales and risk (e.g. knowledge/capacity of regulator, uncertainty associated with approvals process for complex or highly innovative technology);
- the difficulty in finding enough of the right kind of start-up investment at key milestones during the Development Cycle;
- barriers to scaling up (e.g. finance, risk, energy supply and skill shortages);
- identifying and stimulating markets at price-points that the industry can afford;
- securing and maintaining public, and therefore political, support; and
- failure of government to intervene on a scale and to the timetable need.

110 Synthetic aviation fuel (SAF) can be produced from carbon dioxide (CO_2) captured from the air or industrial sources, combined with green hydrogen (produced using renewable electricity) to create syngas; this is then converted into liquid hydrocarbons – the building blocks of SAF – through processes like Fischer-Tropsch synthesis (FTS) to create a "drop-in" fuel usable in existing aircraft.

4.4.2 Tables 11-13, which draw upon the same sources as before[111], highlight where these kinds of issues are coming to the fore whilst also noting that it is not simply the absence of enabling policy and regulation, that has already – or seems likely to – impinge on the speed and scale of development of the chosen technologies, but also other external and commercial factors. These include investment business cases and perceived risk, the difficulty of finding and aligning supply chains, scalability and very importantly contention with non-aviation and non-transport sectors for scarce investment and outputs.

4.4.3 In relation to SAF, the hurdles are finding sufficient feedstock and sufficient investment to deliver scaling at the speed to meet the output levels the industry needs to meet its Net Zero targets at the right price. In July 2025 SAF was retailing at over 4 times the cost of Jet A1 (see Figure 24) and that ratio increased as oil prices dropped in September 2025. If it is to be adopted at scale as the fuel of choice by airlines this comparative price relative to Jet AI will need to reduce to less than 2:1 (ideally c1.5), but this will only happen if demand reaches levels which creates opportunities for economies of scale in production. Achieving this transition, is less of a technological challenge now than a commercial one. This is why the UK Government pressed ahead with taking its SAF mandate through Parliament and has provided grant funding to a small number of home-based start-up operations. However, the evidence points to productive capacity being brought online far more quickly in North America, Asia and prospectively Brazil and the Middle East.

Figure 24: Cost of different fuels SAF as a ratio current Jet A1 Kerosene[112]



Source: Northpoint Aviation

111 Our questionnaire survey and those of others, review of industry, academic and government literature, sectoral roundtables and ongoing engagement with key stakeholders with industry knowledge.

112 Comparative market data from July 2025 synthesised from a wide range of internet sources.

4.4.4 Smaller passenger aircraft (15-50 seats) using hybrid, battery powered electric or fuel cell-based power sources to fly shorter sector lengths up to 600km, appear likely to come into service before the end of the decade. The issue will be providing the right source of power (green electricity for batteries and green hydrogen for fuel cells) at a wide enough range of airports to support domestic and near European networks and then getting them adopted by key carriers within their networks and re-skilling maintenance staff to supply the same online support available to Jet A1 turboprops.

4.4.5 As highlighted in Chapter 3, there has been a lack of substantive progress on adapting jet engine technology to use hydrogen (or variants such as ammonia), determining the future storage and logistics of hydrogen, its implications for aircraft design, and the cost of providing a new dedicated infrastructure at airports, hence initial enthusiasm for what was championed as the ultimate green fuel has diminished and timescales for introduction of hydrogen fuelled aircraft have moved materially to the right. The cost and power required to manufacture green hydrogen is also a potential barrier to its early adoption.

4.4.6 While SAF is a core element in strategies for reducing aviation's carbon footprint and has been certified for use in the form of a maximum 50% blend with conventional jet fuel, there are concerns about long-term engine wear, performance consistency, materials compatibility and the need for cycloalkanes and aromatics (which are often deficient in SAF).These are being actively studied, and there is cautious optimism that solutions like synthetic seals and advanced testing protocols will emerge to address them. But, until they do, the industry's push for approaching 100% SAF hinges on overcoming the technical and certification hurdles.

4.4.7 Similarly, there is some exciting progress being made on aircraft design, but not yet game-changing enough to mean new fuels such as hydrogen or battery power can be readily adopted; fortunately, they may be able to be used on conventionally powered aircraft before that.

4.4.8 With regard to airspace modernisation the biggest hurdles are:

- The need for further technological advances in generic digital technology and their successful application to some of the complex problems in the airspace management environment.
- The difficulties of securing efficient interfaces across international blocks of airspace due to the use of incompatible technologies and the importance this places on securing international agreements. In Europe, this is an issue that the SESAR programme has been focused on for many years.
- The cost and likely requirement for some retraining for ATC staff at a time when they are in very short supply.
- Ensuring the latest transponder and satellite-based equipment is fitted into all aircraft and that pilots have the necessary training, in spite of cost and training capacity constraints.

4.4.9 As for customer-facing technologies, these are often smaller in terms of resource commitment, quicker and easier to bring to market and offer tangible prospects of a positive impact on an airports bottom line, making them less dependent on outside Government support. Indeed, many of them are already being adopted, or are in the plans of, larger and wealthier airports like Changi, Heathrow and those serving the USA's top tier cities.

4.4.10 In many cases, even where their technical feasibility has been proven[113], as in the case of satellite launch platforms and e-VTOL and supersonic aircraft, finding investment to secure large scale industrialisation production and markets willing to accept price-points that will bring the prospect of long-term commercial sustainability remains a difficult and high risk enterprise, as demonstrated by the experience of Lillium and Volocopter. Airbus's attempts to develop a hydrogen focussed aircraft programme would not have been affordable but for the significant grant funding provided by EU sources.

4.4.11 In reality, the development of most non-incremental (i.e. step change or disruptive technologies) is a high-risk enterprise. Only where the demand for the technology from within the industry is so great (e.g. SAF), or where the commercial upside is so material that investment has a high chance of being recouped quickly (e.g. biometrics and mobile based virtual reality-based systems), or in some cases its potential to disrupt (e.g. drones and near earth satellites) is so significant that the risk reward balance changes. Will innovators and the established industry be willing to partner to find a potential route to market? only rarely, and in the most incremental of innovations, is this entirely funded privately. Much more commonly, the scale of the financial costs/risks involved, or shortages of key materials/skills involved, or the uncertainty about whether the projections about whether the form, size and timing of commercial markets will ever be realised means external assistance, typically from public sector sources or regulation, will need to be secured before progress can be made.

113 Or is likely to be in the near future.

5. The Roles of Government

5.1 The Relevance of Government

5.1.1 Although aviation is a private sector industry, Government involvement is significant and unavoidable. Such is the nature of aviation and its importance to national and international mobility, the economy, security and international relations, that regulation – and selective government support – is a necessity. This is to manage a wide range of issues, including safety, environmental standards (including noise, pollution and carbon emissions), the management of airspace, the need to agree international aviation standards and protocols, and how to grant planning approval for major infrastructure.

5.1.2 These core regulatory roles are an inevitable and continuous part of managing aviation, but Governments have some discretion in how they use them. For example, regulations can exert a tighter or looser control over a particular aspect.

5.1.3 Furthermore, Governments often have specific longer-term policy goals. These currently include encouraging economic growth through improved connectivity, tackling climate change and improving environmental standards by reducing CO_2 emissions and other measures, and ensuring that the UK maintains its position as a leading player in this key industry.

5.1.4 If we accept that government intervention, facilitation and co-ordination is a necessary pre-requisite for the full realisation of a such large and complex programme of innovation as supporting new aviation technologies, the next question is how the Government uses its role.

5.1.5 To do this the Government needs to develop a strong understanding of:

- The component sub-sectors of the industry where the UK is already competitive, or has the potential to be, as incremental or evolutionary technologies are easier to bring forward than new or revolutionary ones[114].
- The new technologies where the UK either has a lead or is aggressively seeking to position itself as leading innovation (e.g. SAF, AAM, Air Navigation and Regulation).
- The maturity level individual technologies have reached, and the scale of up-front investment required to industrialise them and reach the critical mass required to achieve commercialisation.

114 This is the sphere where Aerospace Technology Institute plays a key role, funded in a joint £2bn programme by government and industry.

5.1.6 In an innovation-led environment, those responsible for developing or nurturing innovations frequently advocate for a more libertarian, low-cost approach to regulation – their preference is for light touch or no regulation. However, without appropriate regulation the effect would be to put their interests ahead of other legitimate considerations such as safety, damage to the environment or property, infringement of privacy, or disturbance of the public realm. Government therefore needs to create a balanced policy environment where there is:

- a clearly defined set of essential safety and environmental standards
- a clear policy framework setting out short and long-term strategic priorities;
- a level playing field in terms of the competitive environment; and
- both space and incentives to innovate.

5.1.7 All of this to enable investment decisions can be made with confidence. However, in addition to nurturing innovation, recognising the importance of protecting environmental, safety and security standards, guarding against anti-competitive business practices and seeking to build sectoral resilience, a good regulator must also reassure consumers and give them confidence. They also need to ensure the cost of regulation is not disproportionate and that it can be exercised within appropriate timescales.

5.1.8 Striking the right balance between too much Government involvement and regulation ('less red tape') and too little ('unfair competition', 'lack of clarity for investors') is inherently difficult. In a complex and high-stakes sector such as aviation the balance may shift as the technology develops: maximum flexibility and freedom at the early stages to encourage exploration and innovation, but clear policy direction and regulatory assurance as technologies mature, to facilitate investment and delivery.

5.2 Issues around Government intervention

5.2.1 There is perennial debate about the pros and cons of Government involvement in industrial development. But there appears currently to be broad consensus that the extremes of both laissez faire and heavy-handed state direction are inappropriate – particularly so in the context of an industry like aviation. Current thinking points to the benefit of a 'triple helix' collaboration between Government, industry and academia, bringing strengths as outlined below:[115]

- **Academia:** Generates knowledge through research and provides education and training.
- **Industry:** Drives commercialization by transforming research into products, services, or processes.
- **Government:** Creates supportive policies, provides funding, and establishes regulatory frameworks to enable innovation.

115 The Triple Helix model emphasizes the power of synergistic partnerships between academia, industry and government in fostering innovation, economic growth, and social development in which each 'helix' plays a distinct yet interconnected role; the model highlights collaboration through knowledge exchange, resource sharing, and joint initiatives leading to the creation of hybrid organizations like technology transfer offices, innovation hubs and Science Parks. See Henry Etzkowitz and Loet Leydesdorff; "The Triple Helix, University-Industry-Government Relations: A laboratory for Knowledge-Based Economic Development (1995).

5.2.2 These collaborations blur traditional boundaries, allowing universities to engage in commercialization, industries to contribute to research, and governments to facilitate innovation ecosystems. The model has also evolved to include variations like the Quadruple Helix (adding civil society) and Quintuple Helix (incorporating environmental sustainability).

5.2.3 The Triple Helix model's principles are relevant to the ongoing work of the new Jet Zero Taskforce to achieve the UK's net zero ambitions in the aviation sector. Other examples include the Aerospace Technology Institute and AAM programmes under the umbrellas of Innovate UK and the Connected Places Catapult.

5.2.4 Funding for such initiatives is a perennial issue and respecting the notion that the user pays may need some deftness in its application, to avoid disproportionate cost issues[116] and creating upfront disincentives to invest, for example in SAF production, carbon capture and the generation of green hydrogen. Post-Covid19 the industry's ability to invest speculatively in new technology has been severely curtailed, as there remains a significant debt 'hangover' from losses incurred during the pandemic. As a result, securing their commercial participation may need pump priming.

5.2.5 Currently SAF and hydrogen fuels, AI and AAM are benefitting from Government engagement, but the scale – particularly of funding commitments – remains relatively small, at least by comparison to programmes elsewhere such as the EU. In China the sector is in the hands of state-run programmes and companies with major government equity.

5.2.6 As the DfT Public Bodies review has highlighted, the CAA as regulator for the sector has also recognised that it can play a valuable role in facilitating innovation, while still maintaining its core regulatory functions[117]. This is because regulation, when applied deftly, but flexibly and iteratively (we discuss this a greater length in the next chapter) can be very important in this industry in a number of ways:

- **The Value of Regulation:** while less regulation may seem conducive to innovation in the conceptual stage, mature operations and major investments require regulatory clarity.
- **The Significance of Safety Standards:** aviation is held to a higher safety standard than other modes of transportation, necessitating robust regulatory frameworks[118].
- **Balancing Interests:** pioneers may prioritise innovation at the expense of other issues such as public safety and privacy. Well-framed regulation will ensure both can be achieved.

5.2.7 Government will often have strategic policy objectives – for example on environmental standards – which go well beyond the immediate business objectives of individual commercial companies. They also have potential policy instruments such as fiscal incentives or disincentives, mandates, and direct regulatory or other controlling measures – which they can use to encourage progress. Examples include reduced noise contours and better enhanced noise mitigation around airports in the UK achieved as the result of Government making clear policy expectations or imposing specific restrictions at those airports.

116 Smaller enterprises have less scope to invest in new technologies because of their scale and resource availability.

117 https://www.gov.uk/government/publications/civil-aviation-authority-public-body-review-terms-of-reference/civil-aviation-authority-review-report (2023).

118 Concerns include air rights, operations intensity, proximity to densely populated areas, and data privacy.

5.2.8 In conclusion, while government interventions hold potential benefits, careful consideration of the risks and challenges is essential. Striking a balance between targeted support and market-driven forces is crucial for effective economic policy. Moreover, fostering collaborations and partnerships can enhance the success of economic development initiatives.

5.3 The Current Government Framework

5.3.1 The Government fulfils its role through various structures. These include permanent arrangements including membership in international bodies such as the International Civil Aviation Organisation (ICAO), and national entities including the Department for Transport (DfT), the Civil Aviation Authority (CAA) as lead regulator, and NATS – the latter being responsible for an outsourced national function to manage air traffic that passes over the UK[119]. Local authorities also play important roles, particularly when responsible for major airports in their jurisdiction. A guide to these different levels of structure is given below.

Table 15: Principal Aviation Institutions and Stakeholders

International	Devolved Administrations, Regional and Combined Mayoral Authorities:
ICAO, Eurocontrol, IATA, ACI, International Standards Organisations Global harmonised standards and agreements wherever possible.	Strategic planning, transport & logistics integration, traffic & congestion, economic development & job creation, skills & training, inward investment, Enterprise Zones & Freeports.
UK Government and Agencies	**Local Authorities:**
DfT, CAA, UK Space Agency, UKRI, Catapults • Legislation (Industrial strategy, airports policy, airspace management, data protection, IP, privacy, transcribing ICAO and European standards); • Fiscal (investment, taxation, trading rules & sectoral/regional networking); • Regulation (licensing; certification, anti-trust, delegated authority, environment).	Use of technologies in service delivery, land use planning, environmental compliance, social licensing rules, enforcement, innovation/incubation centres, employment clusters, business rates.

Source: Northpoint Aviation

119 ICAO (International Civil Aviation Organization): A United Nations agency, established under the Chicago Convention, formally known as the Convention on International Civil Aviation (1944), that sets common global standards and regulations.

Policy-orientated structures

5.3.2 The UK Government works with and draws from a diverse range of organisations – some long-standing and some more task-and-finish in nature – in order to address the policy and regulatory needs of the industry. The key bodies are as given below.

5.3.3 The UK Aviation Futures Forum, renamed from the Aviation Council and operating as of 2025, serves as a key collaborative platform between government and industry to address aviation sector challenges and secure its long-term viability. Its role involves fostering partnerships to drive innovation and policy alignment across the sector.

5.3.4 The Jet Zero Taskforce, which succeeded the Jet Zero Council in November 2024, has ongoing plenary and expert group meetings, provides strategic leadership for decarbonizing UK aviation through a holistic, outcome-focused approach involving government and sector stakeholders. Chaired by the Transport Secretary, its role is to identify and overcome barriers to innovation and economic growth. Aims include accelerating the development and deployment of sustainable aviation fuels and zero-emission aircraft to enhance environmental sustainability, pursuing efficiency gains across the aviation system to cut emissions including non-CO_2 impacts, and addressing energy demands.

5.3.5 The Future Flight Challenge (FFC) was a UKRI funded programme from 2019 to 2024 with £125 million in public investment and £175m million from industry. Delivered in 3 phases, the FFC was a catalyst for demonstrating and scaling innovative aviation projects with the aim to establish UK leadership in advanced flight. It funded numerous consortia of businesses and researchers to integrate new technologies and aimed to promote:

- Environmental sustainability via electrification, autonomy, and greener propulsion.
- Reduced congestion and inefficiencies through upgraded air traffic management and digital systems.
- New modalities like flying taxis, drone deliveries, and all-electric aircraft to enhance mobility, connectivity, and reduce carbon footprints.

The FFC was formally closed in May 2025 with the publication of a final evaluation[120] which highlighting how the programme played a pivotal role in accelerating UK innovation in advanced air mobility, electric aviation, and drone technologies by driving technological progress, fostering collaboration, and attracting public and private investment.

5.3.6 The Future of Flight Industry Group (FFIG), renewed in 2025 as a joint government-industry body sponsoring the Future of Flight Action Plan, collaborates with stakeholders to oversee and accelerate the adoption of emerging flight technologies. Its role includes establishing working groups for targeted plan delivery and ensuring safe, secure integration across transport modes. Aims focus on maximizing economic and community benefits while advancing environmental sustainability, mitigating congestion, delays, and inefficiencies through innovative solutions, and enabling new aviation modalities such as advanced air mobility to uphold high safety standards and drive sector growth.

120 https://www.ukri.org/wp-content/uploads/2025/05/IUK-060525-FrontierEconomics-FFC-FinalEvaluation-040425-MainReport.pdf.

5.3.7 The Connected Places Catapult, an innovation accelerator and thought leader in transport, engages in aviation through research, market forecasting, and program delivery for government initiatives like skills strategies and tech funding. Its role includes collaborating across ecosystems to identify future needs and support adoption of connected technologies. Aims encompass promoting environmental sustainability via autonomous and connected systems; reducing congestion, delays, and inefficiencies in air transport through integrated solutions; and introducing new modalities like drones and advanced mobility by enhancing skills, security, and connectivity to drive innovation and sector efficiency.

5.3.8 The UK Research and Innovation (UKRI) acts as the UK's primary research and innovation funding body through entities like Innovate UK. It plays a central role in aviation by investing in projects that propel technological progress and industry transformation. Its aims include bolstering environmental sustainability with funding for low-emission technologies and greener aerospace innovations; addressing congestion, delays, and inefficiencies via support for autonomous systems and efficient operations; and facilitating new aviation modalities like drones and electric vertical take-off vehicles through programs such as the £125 million Future Flight Challenge to foster economic growth and global competitiveness.

5.3.9 The UK Space Agency, currently an executive agency as of 2025 but due to be merged with the Department for Science, Innovation and Technology, plays a strategic role in supporting the UK's space sector, including its intersection with aviation-related technologies. While the CAA is responsible for licensing spaceflight activities under the Space Industry Act 2018, UKSA provides policy direction, catalyses investment, and promotes innovation in satellite infrastructure and space-based services. These capabilities underpin aviation connectivity, navigation, and mobility, and UKSA continues to support the development of launch platforms and satellite applications that benefit both aerospace and broader transport systems.

Regulators

5.3.10 The Civil Aviation Authority (CAA) is the UK's aviation regulator. It is a public corporation established by Parliament to ensure the aviation industry meets the highest safety standards, alongside additional responsibilities including security, consumer protection, and environmental sustainability. It has a global reputation as an outstanding regulator built over a long period, known not only for influencing global aviation standards but also the care and equanimity in its decision making. The CAA works closely with other regulators whose remits impinge on aviation, including the Environment Agency and Health & Safety Executive, and standards-setting bodies such as the British Standards Institute (BSI) and EUROCAE[121].

5.3.11 In 2019 the CAA formed its Innovation Hub responding to the need to bridge the regulatory gap between innovation and established regulation. Since its establishment the Innovation Hub has improved access for innovators to CAA expertise, guidance, and viewpoints on regulations. It has helped to maximise the readiness of organisations seeking approvals for their demonstration of their aviation systems, while also accelerating the development of new policies and regulations by anticipating potential regulatory obstacles in areas of innovation.

121 EUROCAE – Driving the standard of aviation, https://www.eurocae.net/.

5.3.12 The Regulatory Innovation Office (RIO) is a UK government body established in October 2024, under the auspices of the Department for Science, Innovation and Technology (DSIT), and chaired by Lord David Willetts. Its primary aim is to accelerate the adoption of cutting-edge technologies by reducing regulatory barriers and speeding up approval processes, thereby fostering economic growth and positioning the UK as a global leader in innovation.

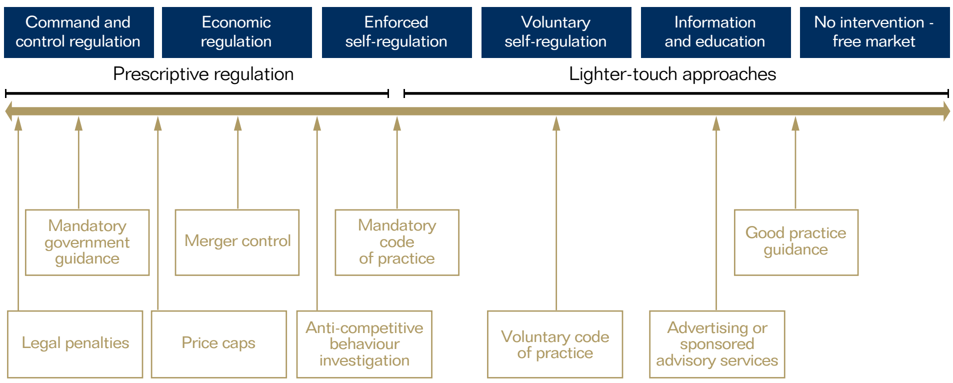
5.4 Government Instruments

5.4.1 Governments use various instruments to fulfil their oversight roles for aviation. Different Governments are at liberty to use these instruments depending on their policy objectives. These are not normally available to other parties and include the ability to generate legislation and legal obligations, as well as creating and guiding regulatory bodies.

5.4.2 Furthermore, the Government is well placed to provide financial support to achieve specific goals, especially where this might not be forthcoming from the private sector due to concerns about risks and timeframes, or where essential infrastructure is needed but might not be commercially viable enough to be supported by the private sector. The Government can also create fiscal incentives and disincentives to shape behaviour, and develop direct mandates and controls over developments, such as through the planning system.

5.4.3 Regulation can manifest itself in various forms, from strict and prescriptive rules with robust enforcement mechanisms, principles-based frameworks, and lighter-touch strategies employing guidance and codes of practice (see Figure 25 below) and even incentives. Often, multiple approaches are utilized within a single regulatory framework.

Figure 25: Approaches to regulation[122]



Source: *Principles of effective regulation* (2021). National Audit Office

122 Reproduced from Principles of effective regulation (2021): p.8. National Audit Office. https://www.nao.org.uk/wp-content/uploads/2021/05/Principles-of-effective-regulation-SOff-interactive-accessible.pdf

5.5 Meeting the Policy Challenges

5.5.1 It is clear from the above that the Government is actively pursuing a wide range of initiatives, including several closely focused on the challenges highlighted in this report. However, the 'governance' framework for this range of projects and programmes is extremely complex and probably unclear to many. Even the term 'Government' is somewhat simplistic: in practice, a wide range of Government Departments (Transport, Business, Science, Energy and of course the Treasury) as well as several subsidiary bodies are closely involved.

5.5.2 This complexity is mirrored in the industry itself. One of the most significant steers from the stakeholder roundtables we undertook during the research for this report, was a general recognition that aviation is a 'system of systems', and that no single actor – or even group of actors – can alone make the changes necessary. There was strong recognition of the need for collaboration, co-ordination and leadership from government, and that was from all parts of the aviation and research ecosystem. The following graphic summarises what role the state (in all its forms) and regulators need to play to support and enable the industry to respond to this challenge.

5.5.3 A 'system of systems' approach by the Government is helpful to address these challenges. There is encouraging evidence that the new Government recognises the need to accelerate support for new technologies, as is evident through the promotion of schemes to increase the availability of SAF. However, concerns remain that Government intervention is rather limited, and aviation initiatives are not sufficiently joined up. It will be important for the Government to clearly determine where aviation fits into wider economic, industry and decarbonisation strategies.

5.6 Models for implementing policy

5.6.1 Having identified the importance of the Government's role in overseeing aviation policy, and the structures it has at its disposable, what possible models can the Government use to address the policy challenges arising from new technologies? In recent years the UK has not had multi-decadal strategies in place (other than pursuing the net-zero carbon objective) comparable to those created in the EU, and this has often resulted in a short-term approach to policy which struggles to address long-term challenges. In addition, policy has often been narrowly focused on a single Department, rather than being joined up across many areas, which has resulted in an inability to fully address wider policy objectives.

5.6.2 There has been increasing interest in developing a 'Mission-Orientated' approach to policy making, and we suggest that this would be an excellent approach to the challenges posed by new aviation technologies. Professor Mariana Mazzucato at University College London, alongside others like Joseph Steigler in the USA, have challenged the orthodox thinking about the role of the state and the private sector in driving innovation and hence enterprise and wider economic prosperity. They have shown how market-shaping policy can be designed in a 'mission-oriented way' to solve major challenges facing society. The benefits of this approach have been increasingly acknowledged in the UK since the 2017 Industrial Strategy[123] and has been reinforced in the Government's 2025 Modern Industrial Strategy[124].

123 Department for Business, Energy & Industrial Strategy: Industrial Strategy: building a Britain fit for the future (2017).

124 Department for Business & Trade: The UK's Modern Industrial Strategy,: (June 2025).

5.6.3 Aerospace historically has been an important beneficiary of this approach, and this has led to several emerging aviation technologies. In all of these, there is acknowledgment that government's role extends beyond just regulation and into proactive facilitation and strategic direction, an approach which Professor Mazucatto has called the 'mission-oriented way'. The Government has acknowledged this in its new Modern Industrial Strategy (2025) as well as in the supporting documentation linked to each of the 8 priority sectors identified, including aerospace[125].

5.6.4 With this in mind, Appendix D '(available separately online – for details see p.137) sets out some initial thoughts on what and overarching Mission for the UK's aviation technology sector might look like, although clearly it will be for Government to develop its own cross-department thinking on this matter.

5.7 Conclusion

5.7.1 Although aviation is a highly complex sector, with extensive (although not comprehensive) private sector participation – which it is envisaged will continue – the Government unavoidably plays a crucial role in oversight. Some of this role is permanent, for instance using regulation to ensure minimum standards for safety and noise. However, at a time of fundamental change in the industry, the key technology areas identified will also require the Government to play a positive, pro-active role to enable the industry to achieve its goals and to manage the wider policy implications. This is particularly important in relation to technologies where the private sector alone will struggle to make headway in the timescales desired by Government, such as in the urgent need to scale up the use of SAF in order to meet decarbonisation targets.

5.7.2 Moving forward, therefore, policymakers and regulators need to anticipate the policy and regulatory issues associated with widespread adoption of new technologies and prepare for the changes accordingly. The Government will need to work collaboratively with the industry and wider stakeholders, primarily as a facilitator of change rather than adopting a more dirigiste top-down directive approach, to achieve this.

5.7.3 It will mean, for example, playing a key role in whether these technologies get to market fit for purpose in a timely manner, having overcome all the necessary compliance and licensing hurdles and with a coherent framework of policy and procedures in place to underpin future operations. In an uncharted technological landscape, it is a significant task to develop legislation and regulation that is light touch, yet timely, proportionate and well targeted. It is difficult balance to get right. However, the Mission-Orientated framework, which the Government has adopted extensively elsewhere, could be a valuable tool for Government to address the challenges. We return to this in the next chapter.

125 Department for Business & Trade; Advanced Manufacturing Sector Plan (June 2025).

6. Addressing the Policy Impacts of New Technologies

6.1 Introduction

6.1.1 As has been highlighted in the preceding chapters, new aviation technologies bring a range of policy issues and challenges for Government to address. We have also explored the reasons for Government action, and the structures and models at its disposal to address these complex policy challenges. In this chapter we will explore what is needed to address these challenges, and outline ways forward for Government.

6.1.2 It is important to note that the UK Government has already made important steps in the right direction, including policy and fiscal interventions in relation to new Aviation Technologies. These include:

- Financial support to incentivise the scaling-up of SAF by the private sector.
- Programmes and funding to encourage investment in electric propulsion.
- Development of new navigation procedures as part of a commitment to airspace modernisation.
- Putting in place conditions to stimulate a fledgling satellite launch industry.

6.1.3 However, there is much the UK can still do improve its competitiveness and market penetration in this sphere. The following discussion will keep in mind the aims of maintaining our third place ranking in aerospace and air transport and realising our ambitions to create a thriving aviation technology sector. It is also important to remember the international nature of aviation complicates policy making, and that goals can be in conflict. For instance, the economic growth associated with growing aviation demand currently conflicts with decarbonisation goals and poses challenges in managing congestion.

6.1.4 This chapter outlines how we think the policy challenges identified in earlier chapters can be addressed. It is structured around the key technology groupings of environmental sustainability, congestion and customer experience, and new mobilities, that were discussed in previous chapters. This is followed by a discussion of various generic issues which the Government will need to address in relation to technological innovation in the aviation sector. These issues are often cross-cutting and require a broad policy approach.

6.2 Making Aviation Sustainable (Technology Group A)

6.2.1 This is the most high-profile and urgent of the policy challenges identified, given the immediacy of the climate challenge and the need to reduce carbon emissions to meet the Government's targets. As has been seen, a wide variety of initiatives are underway across the industry to bring technology to bear on environmental problems, from a continued focus on airframe and wing design, to new forms of propulsion and sustainable fuels. The concern, despite the focus the industry now has on this challenge, is that the promising technologies may either prove difficult to commercialise at costs acceptable to the industry – and ultimately to customers – or where in practice timelines prove significantly longer than needed to achieve key objectives, particularly decarbonisation.

6.2.2 Aircraft noise is also a significant problem, particularly for communities and institutions close to airports, such as schools, hospitals, care facilities etc. Sleep deprivation can be linked to adverse health outcomes. Although there have been substantial reductions in the noise generated by individual aircraft, growth in the number of flights risks offsetting this progress. Noise Action Plans aim to reduce the scale of the impact, and can draw on a range of operational and other tools, including the noise suppression technologies outlined in Chapter 3.

Low-carbon Fuels

6.2.3 There is a growing consensus that there are three key technologies with a role to play in decarbonising flight. These are: electric batteries or fuel cells for smaller planes with ranges of under 600 miles; SAF which could be used in most existing planes relatively quickly if it can be sourced and delivered at scale and at an affordable cost; and hydrogen as a likely solution in the longer term beyond 2050. Most believe that SAF is the highest priority for the next couple of decades, but all three approaches need to be pursued vigorously if the huge challenge of decarbonising aviation is to succeed.

6.2.4 There are still significant research and development challenges, for example, increasing battery power-to-weight ratios, manufacturing hydrogen cleanly, and the design of hydrogen jet engines. But the main issues now facing the industry are about the costs and practicalities of commercialising and implementing the technologies at a price that the industry can absorb and, when passed onto passengers, that they will be willing to pay.

6.2.5 Some examples of these challenges include:

- All sustainable power sources need sustainable sourcing and feedstocks. This raises difficult questions around sourcing and prioritisation: should this be left to market forces, or should hard-to-decarbonise sectors such as aviation be given some kind of priority?
- Most new power sources (and to a lesser extent SAF) will require new physical infrastructure to and at airports for distribution and storage: how will this investment be financed and rolled out?
- SAF is currently much more expensive than conventional fuel: can costs be reduced so that it becomes commercially viable, and who ultimately pays?
- Electrification and hydrogen power cannot be used in existing fleets, so could only be introduced gradually as part of fleet replacement cycles.

6.2.6 The aviation sector is struggling to find sufficient refining capacity to meet even the current demand for SAF, let alone the exponentially higher levels that are likely to be required to achieve Net Zero by 2050. The problem is fundamentally how to create the right long term commercial environment for investment in the expensive plant needed to produce SAF at scale, and then how to keep on increasing it as demand grows. And that is before the challenge of ensuring SAF is available at most major airports, so that airlines who commit to using it, and in so doing reduce their prospective Emission Trading Scheme[126] payments, can be sure it is available across their network.

6.2.7 The same issues will arise in relation to the production of hydrogen, but with the added complexity that it will not be a drop-in fuel like SAF, but one requiring its own delivery infrastructure and very probably reconfigured aircraft designs to accommodate the greater volumes needed to address its lower energy density. The new infrastructure required to handle hydrogen as a fuel must be planned at an early stage.

6.2.8 Speaking at the 26th World Energy Congress in Rotterdam, Brian Moran, chief sustainability officer at Boeing, said in April 2024 that:

"SAF is highly unlikely to ever reach price parity with Jet A1 fuel, so there is a green premium. We are working towards bringing the price down. The carbon price is coming up, increasing the cost of Jet A1 and through scale we are trying to bring the price of SAFs down."

126 The UK Emissions Trading Scheme creates a market-based carbon price for the sector's emissions, incentivizing airlines to invest in lower-carbon technologies and energy efficiency to meet emission reduction targets.

6.2.9 Many of the challenges cannot be met by the aviation industry in isolation and need to be treated as a difficult, but essential, part of the wider decarbonisation agenda by policy makers. As well as its essential role as the convenor and facilitator of change, the Government – working with the industry – needs to give clear leadership and policy direction. Given the difficulty and urgency of the decarbonisation challenge, it also needs to draw on its full range of policy levers. These may be positive, such as financial leverage to kick-start or support key investment gaps. But more directive measures may well also be needed, such as mandates (already being introduced to promote the adoption of SAF); explicit limitations on high-carbon flights (analogous to the long-standing noise restrictions at some key airports); and fiscal incentives or disincentives, which Governments have thus far been reluctant to utilise but which should not be ruled out in future.

6.2.10 Although SAF is the most immediate priority for new fuels, it is not enough on its own to meet future Net Zero targets. It is vital therefore, that the Government simultaneously helps the industry to press forward urgently with electric, hybrid and hydrogen power sources as well as other key technologies such as airframe design and noise-reducing technologies. Within this wide scope, it is important to decide where UK should take a leadership role, where we should let others path find and take advantage of their experience and where we should work collaboratively – particularly at an international level.

6.2.11 Customers also need the best possible information to guide their travel choices. For example, the information currently available about emissions from aviation (and other modes) is relatively crude, based on the total fuel used at each point of departure and attributed to individual flights etc based on 'representative' models. More accurate and useful information (for the industry as well as customers) would be based on more direct measures of the emissions of individual routes and journeys. And while offsets remain an unavoidable element in the overall aviation decarbonisation strategy, customers and the wider public also need robust monitoring and clear information about the authenticity and reliability of the offsetting data.

6.2.12 Accurate data is also vital for the modelling used by the DfT and others, including the Climate Change Committee. It provides the necessary underpinning, e.g. for designing incentives to encourage more sustainable flight and for monitoring by the industry, Government and the wider public.

Challenge Responses and Solutions

6.2.13 Table 16 below provides a summary overview of how the industry's most important challenge, certainly the one with the greatest existential threat, can be tackled and the technological innovations to support it. It provides encouragement for future success because, despite the recent reset of the timescale for introducing hydrogen powered jet aircraft (it is now going to be a post 2050 technology) there does appears to be a concerted effort between the industry, ICAO and national governments to tackle the problem and the emergence of a coherent and deliverable pathway, driven by SAF, that will allow them to do so.

Table 16: Policy, Regulatory and Technology Responses to Aviation Industry Challenges (and Opportunities) (Priority A)

Challenge	Required Response	Possible Technology Solutions
A: Reducing the Environmental Impacts of Aviation – Smaller Noise Footprints and the achievement of Net Zero CO_2	**Reduce CO_2 Emissions:** Achieving Net Zero CO_2 emissions is imperative for mitigating the environmental impact of aviation.	**Low carbon Fuels:** Invest in R&D of sustainable aviation fuels (SAF), electric propulsion, and hydrogen-based technologies. ATC routing.
	Noise Reduction: Materially reducing airport noise footprints is essential for minimizing the adverse effects of aviation on surrounding communities.	**Advanced Engine and Airframe Design:** Develop more fuel-efficient engine and airframe designs to minimize fuel consumption and emissions, ATC routing.
	Capacity Enhancement: Optimizing departure routes, vortex separations, and flight routings can increase capacity while simultaneously reducing CO_2 and noise emissions.	**Advanced ATC Systems:** Utilize precision navigation systems (R-Nav), AI machine learning, and quantum computing to optimize ATC routing and support increased cockpit autonomy for efficient gate-to-gate operations.

Source: Northpoint Aviation

6.2.14 The main uncertainty is not primarily about the technologies (and other operational developments) to enable decarbonisation, but whether they can be deployed at the scale and speed needed to meet specific net-zero target dates. Both the industry and Governments are working to tackle this challenge[127], and a recent report by the Aviation Impact Accelerator (AIA) at Cambridge has identified four specific initiatives[128], which if undertaken before 2030 would help deliver the goals[129]. But there is not yet the proven track record of delivery to reassure sceptics.

127 Speech by UK Chancellor of the Exchequer, Rachel Reeves, 29 January 2025, https://www.gov.uk/government/news/government-backs-heathrow-expansion-to-kickstart-economic-growth

128 Relating to contrail reduction, system-wide efficiencies, SAF and moonshot demonstration programmes designed to rapidly scale transformative technologies.

129 Aviation Impact Accelerator -Cambridge University: Five Years to Chart a New Future for Aviation (Sept 2024).

6.2.15 This has led the Climate Change Commission in the UK to adopt more conservative assumptions about the take up of key technologies like SAF and other clean forms of propulsion, and therefore to argue for greater emphasis on non-technological measures[130] such as demand management, taxing aviation fuel or rationing seats of frequent fliers in the busiest markets[131].

Specific issues for further review

6.2.16 There is a need to make better quality data available on emissions from aviation and to do so in a form that can allow direct comparison with other modes. This requires accurate source data based on direct energy usage by power units of each mode of transport, not conversion factors derived from bunkering inventory and presented in the form of representative aircraft, rolling stock, vehicles or ferries. It also requires bottom-up modelling that can reflect the unique dynamics (e.g. distance, topography, load factors) of journeys between two points or collectively a network of such single route assessments aggregated together.

6.2.17 If smaller airports are also to contribute to the decarbonisation of the aviation sector – and there are good arguments to suggest that they should – then the Airports Council International (ACI) Carbon Accreditation process offers a systematic route for them to do so, leading ultimately to partnerships with fuel suppliers and airlines. But the fragile finances of such airports post-COVID means that they may require third party support to make the kind of investments needed to reduce their Scope 1 and 2 profiles to Net Zero by 2050.

130 Including (positive) financial incentives, or regulatory levers such as prohibiting non-electric small planes for short/medium journeys.

131 Climate Change Commission: The Seventh Climate Budget (February 2025).

6.3 Tackling Congestion, Delays and Inefficiencies (Technology Group B)

6.3.1 The second cluster involves technologies to address customer experience issues, including airspace modernisation to reduce congestion, improve reliability and provide better services through more efficient operations. Modernising air navigation and airspace are crucial for enhanced capability and capacity. There are limits to how far air traffic controller workloads can be increased, meaning that the introduction of AI and quantum computing based technologies in the air and the control room will be critical to future growth, as will be the adoption of better integrated technologies and systems across national airspace boundaries – a key objective of the EU's CESAR programme.

6.3.2 The UK Government has asked the CAA, ACOG and NATS to lead work on the modernisation of UK airspace: the latest iteration of the deployment plan for that strategy was published in August 2025[132]. The CAA is also seeking industry views on how AI can most usefully be deployed across the sector[133]. Meanwhile in the airport and on the ground, a wide range of customer-facing technologies are now being introduced (see Chapter 3).

6.3.3 However, new challenges will also arise from the introduction of drone and AAM flights, increased BVLOS drone operations in lower airspace and integration of these with general aviation and air sports users. Expanding digital mapping for flight planning and putting in place standardised procedures for operating in lower airspace to replace disparate local by-laws will be important for encouraging growth and securing societal buy for the new modes. Government and the CAA will need to ensure these laws are applied consistently and that the necessary resources are available.

6.3.4 Addressing these challenges requires a more coordinated approach to airspace, airport, and land use planning, along with robust environmental protections, than is currently in place: this is a major concern for local authorities and community groups. Such integrated planning efforts are vital for building social acceptance and market confidence in new aviation technologies. By fostering collaboration between regulatory authorities, industry stakeholders, and other relevant parties, governments can ensure the safe and efficient integration of emerging technologies, while addressing public concerns and environmental considerations.

6.3.5 As discussed earlier, passenger facing technologies have a good track record of finding their way to market and being accepted by the travelling public. There is no real policy gap requiring intervention here in the case of larger airports. However, providing support or incentives for their take up at smaller airports with modest capital budgets could help their wider introduction, helping passengers and the airports themselves.

132 CAA: Airspace Modernisation Strategy Part 3 – Deployment Plan, 2nd Edition; CAP 1711b (Aug 2025).

133 CAA Call for Insights: Quantum Computing Technology Application in Aviation (Aug 2025).

Challenge Responses and Solutions

6.3.6 Tackling problems associated with congestion and airspace are, alongside the disruption caused by Black Swan[134] events, at the forefront of the industry's strategic thinking. Those problems are to be found in the sky in the form of flight delays or on the ground in the form of queues for check-in, security and border control and long processing times for cargo. Table 17 below outlines how technology can be used to address these challenges

Table 17: Policy, Regulatory and Technology Responses to Aviation Industry Challenges (and Opportunities) (Priority B)

Challenge	Required Response	Possible Technology Solutions
B: Tackling Congestion, Delays and Inefficiencies	**Airspace complexity and congestion lead to delays and unreliability in air travel** Affects both passengers and cargo airlines. It also results in delays and indirect routings increase GHG emissions. The response required comes in the form of Airspace Modernisation and enhanced air navigation systems to increase capacity in controlled airways optimize routings, maintain safe operations.	**AI, machine learning, and quantum computing** to help optimize departure/ arrival sequencing (on the ground and in the air) and facilitate deconflictions and manage Terminal Management Areas associated with busy airports or the complex airport systems that serve large cities.
	Improve passenger experience and automation of freight handling. Processing both types of traffic at airports creates bottlenecks. Streamlining passenger flows, even as airports get busier, will help maintain a positive perception of air travel for users. While better digitalisation of air cargo and increased automation of freight handling at UK airports will help improve reliability and delivery times for UK shippers.	**Biometrics** to speed passage through security and border control, AI led virtual reality to guide passengers to their gates and retail opportunities and automation and robotics for handling cargo.

Source: Northpoint Aviation

6.3.7 While technological solutions such as biometrics, AI, automation and virtual reality are already being used to bring some relief for passengers and cargo shippers, the underlying issues remain and require major investment in the latest air navigation infrastructure and airspace redesign. Both are expensive and difficult to roll out quickly. And that was before the level of industry indebtedness and reluctance to invest rose materially during Covid19.

134 Including oil price crises, economic recessions and major terrorist incidents

6.3.8 Sustained UK leadership in the related fields of technology, expertise and service provision, will need support and leadership by the Government, along with international partners, and supported with appropriate policy direction, regulation and incentives. It is a field where the aviation industry needs to work with, and learn from, those leading in the digital arena.

Specific issues for further review

6.3.9 The importance of generic digital technologies such as AI, machine leaning, quantum computing and robotics, to address many aspects of future airspace management and airport operations is being recognised. This was evident in the CAA's recent AI strategies, aimed at mitigating – directly or indirectly – congestion, delays and deteriorating service standards[135]. But such is the complexity of the technology and its potential to increase the efficiency and reliability with which passengers pass through airports and reduce the delays experienced by aircraft en-route, on final approach or departure and on the ground, that we suggest an Expert Commission be appointed to provide advice and monitor progress.

6.3.10 To complement this the Government should incentivise the introduction and take up of these customer facing technologies by supporting NATS through its licensing process; the CAA through the direction of the Secretary of State for Transport; and, in the case of airlines, using requirements imposed through their annual update of the Air Operator's Certificate (AOC) and tax breaks on investment in the necessary hardware and software.

6.4 New Aviation Modalities (Technology Group C)

6.4.1 Perhaps the most disruptive of the new technology groupings will be the advent of new modalities, including drones[136]. Although the expansion of drone use appears to be advancing well in areas such as environmental infrastructure, survey work and various 'blue light' uses, progress has been uneven. While regulatory frameworks are evolving to support innovation, many operators face challenges articulating the specific hazards associated with their operation. In reality, the pace of development reflects the balance between the need for clearer and more efficient regulatory guidance, and the growing maturity of a nascent sector that is still developing its operational and safety culture. The CAA's new standardised operational risk assessment (SORA) procedures have improved matters, and there are encouraging signs that the sector itself is maturing, with operators increasingly engaging with the complexities of risk and safety management. There is also an urgent need to drive forward the diversification of 'use cases', introduce larger fixed-wing drone operations (e.g. for delivering freight to remote areas), engage local government pro-actively with the opportunities drones can provide, whilst treading carefully in line with societal acceptance, e.g. on household deliveries by drone.

135 CAA: CAP3064 – CAA's Response to Emerging AI-Enabled Automation (Nov 2024) and CAA: CAP3064A Part A – Strategy for Regulating AI and Advanced Automation in Aerospace.

136 Also referred to as unmanned aerial vehicles, remotely piloted vehicles, uncrewed aircraft systems, etc.

6.4.2 In terms of c-VTOL and e-VTOL deployment to RAM and UAM markets, progress has been slower with no commercial services yet in operation and some consolidation in the industry as start-ups fail (see Chapter 3). However, the Future of Flight programme has resulted in several successful trials, raised the profile of new modalities, stimulated innovation and secured government engagement and investor interest. But much remains to be done in terms of putting in place supportive policy and regulation, securing appropriate funding, progressing through certification processes, engaging with local government, tacking key citizens' rights issues and raising public awareness.

6.4.3 'While many aspects of AAM development and operations sit squarely within the scope of the CAA's remits, it is not designed to take on an operational approvals' role, beyond certification and licensing of facilities and aircraft. How those aircraft are deployed and used in different environments from rural to urban and coasts to mountains, is arguably not something upon which the CAA should be asked to make decisions – although it will inevitably have a consultative or advisory role. These decisions sit more appropriately with national and local government, informed by market dynamics and community needs, and supported by a coherent policy framework that enables safe and socially acceptable integration of new aviation modalities.

6.4.4 Local authorities regard land use/planning, environmental impacts and public realm effects, as their responsibility. Currently some confusion over decision rights exists that need to be quickly resolved to maintain industry and investor confidence in the sector. Integrated local development and transport plans, offering a clear vision for AAM in a particular locality, are a priority. Relying on an ad hoc development led system, that does not consider local issues or objectives, is not the way forward.

6.4.5 In relation to e-VTOL, OEMs are showing signs of refining their approach to commercialisation. Rather than relying solely on bespoke infrastructure such as vertiports with associated car parks and power supplies, a study by the UK Air Mobility Consortium in 2022, in collaboration with the CAA[137], has explored how existing flight corridors and Visual Flight Rules could support early deployment. Their jointly developed Concept of Operations outlines a phased and pragmatic approach to integrating AAM into UK airspace, focusing on operational feasibility, safety, and public acceptability, without dependence on a fully built-out vertiport ecosystem.

137 https://www.eveairmobility.com/uk-consortium-completes-urban-air-mobility-concept-of-operations-for-the-civil-aviation-authority/ .

6.4.6 A crucial issue in relation to new modalities is public concern about safety, privacy and protection of rights. By prioritising citizen rights and engaging in thoughtful regulation, government can foster the responsible adoption of emerging technologies while safeguarding public interests and privacy concerns. The World Economic Forum's Principles of the Urban Sky offers initial insights into addressing these concerns, through the following approaches:

- Assessment of Sector Benefits: Government should impartially assess and balance the benefits and drawbacks of innovations on behalf of the public and national interest. Establishing trusted channels for communicating this assessment to the public should be integrated into broader communication strategies.
- Zoning and Protections: Implementation of zoning, prohibitions, and protections on overflight and congested areas may be necessary. Analogous to restrictions on drones in Australian National Parks or prohibiting jet skis in pristine lochs, these measures aim to balance technological advance with environmental and societal concerns.
- Data Protocols and Privacy: Clear data protocols and sharing agreements are essential for Mobility as a Service (MaaS) to function effectively. Government intervention may be required to navigate contentious issues such as data protection, privacy rights, and the benefits of data sharing. Local authorities and city regions may require support from national government to develop MaaS solutions and ensure consistency nationwide.

Challenge Responses and Solutions

6.4.7 New air mobilities are high profile new technologies that have attracted a good deal of innovation, investment, media coverage and political ambition. It is an area the UK Government is supporting in the form of the Future of Flight and the UK Space programmes, and the build-up of subsidiary units within the CAA. However, the focus is now shifting away from research and innovation towards the commercial roll out of these technologies. This puts the onus more squarely on market making initiatives, fiscal incentives for start-ups, performance-based regulation and the need for dedicated land use planning and approvals regimes upside. If this is achieved, the upside mobility and economic benefits are potentially significant and help the UK retain a foothold in the fastest growing segment of the civil aviation sector.

6.4.8 Table 18 below outlines the policy challenges arising from new air mobilities and some of the responses that will be required. By implementing these strategies and embracing future flight technologies, the Government can enhance service delivery, improve efficiency, and promote innovation in the aviation sector.

Table 18: Policy, Regulatory and Technology Responses to Aviation Industry Challenges (and Opportunities) (Priority C)

Challenge	Required Response	Possible Technology Solutions
C: Realising the Potential of New Forms of Modality and the Opportunity to Disrupt Existing or Create New Aviation Markets	**Increase the number of near-Earth Satellites launched, platformed and controlled from the UK** Facilitate the replacement or repair of aging infrastructure and give the UK a leading role in global monitoring and surveillance – essential for maintaining aviation safety and security.	Develop other cost effective and efficient **vertical (e.g. SaxaVord) and horizontal (e.g. Spaceport Cornwall) launch platforms** licensed by the CAA under the Space Industry Act 2018[138]; also enable low orbit stationary platforms to increase.
	Drones and AAM Systems to address urban congestion and other forms of mobility requirements and service costs in remote and rural areas. Develop better policy guidance, regulation and cost-effective mobility options for the public sector (e.g. blue light operations and logistics alongside mobility for the elderly, disabled and others with special needs). E-VTOL will provide more convenient access for time-poor high net worth individuals and more cost and carbon efficient means of undertaking intra-urban, regional and inter-regional travel.	**Drones** flying with and then beyond BVLOS for surveying and last mile deliveries with larger fixed wing drones for more distant logistics. **Vertical Take-off and Landing (VTOL) Technologies: b**attery, fuel cell or hybrid electric conventional fixed wing (c-VTOL) aircraft using increased numbers of local airports for inter and intra-regional and travel.
	Increased Demand for speed, dynamic convenience, personalisation of air travel, Especially by wealthy individuals, military or VIPs.	**New Supersonic Aircraft** in BusAv 8-seat or commercial 70 seat configuration (e.g. Boom) reducing travel times for those using them.

Source: Northpoint Aviation

6.4.9 The public sector can play a pivotal role as an end-user and catalyst for the implementation of future flight technologies. By leveraging advanced drone and UAV technologies, government can enhance various services and operations:

- **Medical Supply Delivery:** utilizing drones for the delivery of medical supplies to remote areas can improve access to healthcare and save lives.
- **Law Enforcement Support:** aerial surveillance drones can aid law enforcement agencies in tasks such as monitoring public gatherings, traffic management, and search and rescue missions.
- **Infrastructure Inspection:** unmanned aerial systems can be employed to inspect critical infrastructure, providing real-time data on structural integrity and enhancing safety.

138 https://www.caa.co.uk/space/licences-and-permissions/spaceport/.

6.4.10 Consideration should be given to how these solutions can be effectively integrated across national, regional, and local government levels. Government tendering specifications can encourage standardization and elevate standards. A database for public sector AAM tenders would be helpful, and facilitate coordination between different departments and local governments, promoting efficiency and innovation in procurement processes.

6.4.11 The UK government's Future of Flight programme was a significant initiative aimed at advancing aviation technologies, including AAM. This program supported projects related to electric and autonomous aircraft, urban air mobility, drones, and sustainable aviation. However, our consultees expressed concerns about whether the FFC had an adequate budget compared to international competitors. Benchmarking investment into AAM and Unmanned Aerial Systems (UAS) technologies by competitor governments, analysing their plans for supporting commercial rollout of these technologies and where the UK stands in comparison, is important intelligence that needs to be updated regularly[139].

6.4.12 By ensuring robust funding, fostering collaborations, and aligning strategies with international standards, the UK can position itself as a leader in future flight technologies, driving economic growth and innovation in the aviation sector. The Future of Flight Industry Group (FFIG) presents a promising platform to address many of the issues highlighted in this report. To support this the Future Flight Challenge was awarded over £20m of further funding April 2025 to help advance drone and air taxi technologies, with a focus on enabling commercial-scale operations, supporting healthcare, assisting police, and improving delivery services[140]. In September 2025, new Aviation Minister Kier Mather MP announced a £4m Government funding package using the Future Flight programme to support to a series of innovative projects deploying drone technology to transform logistics in offshore energy, healthcare and land restoration[141]. Projects relating to next-generation zero-emission aircraft and the development of vertical take-off and landing technology also received funding.

139 The AAM evidence review prepared by Bryce Tech for DfT in December 2023 is a good example of this.

140 DfT Press Release: Over £20 million to help drones and flying taxis take to UK skies (1 April 2025).

141 Department for Transport: Over £4 million government backing for next-gen aviation technology projects (29 September 2025).

Specific issues for further review

6.4.13 A range of actions will be needed to address these challenges. First, having raised awareness of, and encouraged participation in the nascent AAM sector, through the Future Flight Challenge[142] and the establishment of the Future Flight Industry Group, the priority must be to maintain the momentum that has been created and support the scale of ambition that has been articulated. This will require the Government to:

- Maintain cross-government co-ordination – for example with the **Regulatory Innovation Office (RIO)**[143] work to streamline regulations and remove barriers to innovation.
- Tackle public sector procurement issues that could hold back private sector engagement – e.g. by identifying current and prospective public service requirements for next-generation AAM aircraft.
- Continue investing in the necessary multi-year programme of policy and regulatory development to support initiatives that will help to introduce and scale-up commercial deployment.

6.4.14 The **CAA** should focus on continuing its work on the certification of new technologies (i.e. technical approvals of equipment, proposals and operating companies) and on producing guidance on the technical aspects of UTM design and operations[144] and drone and vertiports development. It should go beyond commissioning trials and help to enable the scaling up of drone and UAM operations. But we should acknowledge that the CAA cannot cover every issue and would be best to focus where its expertise is unique.

6.4.15 **Local Authorities** also have an important role to play, including making provision for drone and e-VTOL infrastructure (including Vertiports) in their development plans and for associated investment and regulation in their Local Transport Plans. Procedures also need to be introduced to consult with them efficiently on major SORA applications that could materially impact upon their jurisdictions. Such engagement could be led by a single authority, by more than one authority acting collaboratively or even at a regional or cross-regional level.

6.4.16 Drone operations, once they achieve critical mass, are likely to need airspace zoning plans that are either permissive or preventative and time or operationally specific, and be sensitive to land uses and receptors on the ground, if their social license to operate at scale is to be maintained. The roll out of digital mapping to local authorities that reflect UTM development may therefore eventually be needed to define operational zones and corridors in the same way as safeguarding zones applied to airports.

142 Frontier Economics: Final Evaluation of the Future Flight Challenge – for UKRI (May 2025).

143 Launched in 2024, the RIO's goal is to speed up the market entry of new technologies is important in key sectors like AI, engineering biology, and drones, drive economic growth, and position the UK as a global leader in innovation.

144 The recent introduction of the SORA (Specific Operations Risk Assessment) based approvals for drone operations and the CAP 3169 e-VTOL Delivery Model guidance (Sept 2025) are two good examples.

6.4.17 As discussed earlier, space is an increasingly important field in which the UK seeks to play a significant role. However, the **UK Space Agency** has been severely criticised by the UK Parliament's Science, Innovation and Technology Select Committee amongst others. The Government has recently announced its intention to bring the Agency in-house as part of the Department for Science, Innovation and Technology. This creates an opportunity to review the future direction of the programme, the investment needed, the extent to which the UK should aim to be self-sufficient or should work in close collaboration with international partners, and ensure it has access to the resources (skills as well as investment) to deliver effectively.

6.5 Cross-cutting Issues

6.5.1 In addition to the main Technology Groups A to C, in earlier chapters we also touched on other new technologies such as hypersonics, cyber security and MaaS enablers (e.g. machine learning, AI and quantum computing) that could all impact the sector and in which UK has a well-developed innovation and business ecosystem. Although the challenges these technologies help to provide solutions for – satellite payload delivery, cyber/terrorist threats and resilience to/recovery from external shocks – are considered less high profile than those under the Technology Groups above, they nevertheless illustrate the scope of the industry issues that technology can help to tackle; and how well placed the UK is to benefit operationally from exploiting our expertise.

6.5.2 In this section, we identify a range of cross-cutting and generic issues. Many of these apply to all the technology groups listed above, or to several issues. It is essential that an overarching strategic approach is taken. It is not enough to have a set of disparate initiatives – important though each is – since many of the policy challenges overlap, and in some cases are also in tension. To manage this successfully, all involved need a sense of the overall strategic direction and goals.

Need for a Better Strategic Framework

6.5.3 Although the UK continues to rank 4th in the world in terms of aerospace exports (£12bn in 2024), second globally in terms of GVA (£10.9bn supporting 0.4% of UK GDP) and third in terms of the size and connectivity of its air transport sector, maintaining this position in the face of challengers from Europe (e.g. France, Germany and Italy), Asia (China, South Korea, Japan and India) and the Americas (USA, Canada and Brazil) will require on-going vigilance and commitment from both the public and private sectors.

6.5.4 Whilst good work is being done by the industry and government to maintain this position, over the course of this review a number of areas of concern have been identified. To address these and maintain the UK's competitiveness in a high value and highly skilled industry we believe that an overarching, coherent strategy to maintain the UK's hard-earned market presence, as well as the jobs, GVA and export earnings associated with it, is required. Whilst the recently published Industrial Strategy[145] and its accompanying Sector Plans provide a helpful backdrop and statement of intent, we believe a strategic framework focusing on the new aviation technologies discussed in this report would make a major contribution. Not having a comprehensive strategy to address these challenges risks ceding our position to competitors[146], all of whom are seeking to grow their presence. It also allows the big three – USA (at least pre the current administration), Europe and China to continue to plan over long timescales and so to consolidate their market position.

6.5.5 The inclusion of aerospace and aviation in a wider range of industries in the Advanced Manufacturing Sector Plan[147] means that there is no longer an explicit sectoral strategy for aviation. Our concern is that this threatens to leave new aviation technologies without the clearly focussed policy framework, which is needed to drive government engagement with this sector. The advantage of such a strategy is that it can promote the transformation of aviation through the deployment at scale of a wide range of new technologies. It also needs to dovetail closely with the Government's wider industrial, trade and decarbonisation Strategies. Our consultees called for aviation to be seen as a 'system of systems' and for a clearer sense of strategic direction in communications.

6.5.6 The current and recent Governments have introduced and supported a number of important (and welcome) initiatives to support the sector, including the Jet Zero Strategy, Airspace Modernisation Plan and the Future of Flight Route Map. However, these are each relatively narrowly focussed in terms of scope and sometimes timescale. Others, including the EU and China, take a longer, more strategic approach.

6.5.7 Moreover, the current arrangements understandably focus, case-by-case, on specific challenges (decarbonisation etc.). Such focus is indeed essential. However, it is clear, that some of the challenges also have significant interdependencies, and that there are important cross-cutting issues which impact them all. We touch on some of these in this section, e.g. core technologies which impact on many areas of aviation, and the need to foster new skills which support the industry broadly. We therefore see significant potential benefits in a broadly-based strategic approach which addresses both the specific individual challenges discussed in this report but also the cross-cutting generic enablers of success.

145 Dept for Business and Trade: The UK's Modern Industrial Strategy (June 2025).

146 The top tier is led by the USA, Europe and China.

147 https://www.gov.uk/government/publications/advanced-manufacturing-sector-plan (updated in August 2025).

6.5.8 A long-term approach is critical. Although government publications covering different technologies and aspects of the aviation tech sector often identify longer term horizons and recognise extended timescales are likely to be needed to meet key objectives, the focus and commitment is often relatively near-term. Programmes and initiatives commonly last 3-5 years (e.g. Future of Flight, Airspace Modernisation), hence projects and funding tend to come forward on an ad hoc – sometimes incremental and on a competitive basis – so that there is no guarantee of long-term financial support from government or its agencies lasting ten years or longer. This is because there is no equivalent to ATI, or a dedicated subsidiary of it, for innovations sitting under the new technologies umbrella. If the UK is to be a global player in high priority technologies like SAF, hydrogen, advanced navigation systems, and AAM, then tentative 'toe-dipping' initiatives and a 'de-minimis' approach to funding will need to be replaced by long term programmes backed by appropriate levels of resources.

6.5.9 Aviation is a global industry, with global supply chains from manufacturing to fuel supply and operations. It therefore needs an agreed system of international standards and operational protocols. This means that the UK cannot plan or operate in isolation and needs to work closely with international partners. It needs to clearly identify areas where it has particular skills, needs and competences, and recognise that there are other areas where it is pragmatically and financially sensible to leave others to take the lead.

6.5.10 Taken together, these considerations lead us to conclude that aviation needs an overarching, mission-focussed, programme, aimed at maintaining UK long-term competitiveness bringing together a coherent set of sub-programmes and projects. The focus, we propose, should be the introduction and deployment – at speed and scale – of the technologies discussed in this report.

Leadership and Governance Champions

6.5.11 To achieve such a strategic plan and mission-focused programme will require strong leadership and appropriate governance arrangements. We recommend the creation of an over-arching group with responsibility for the strategy, to include representatives from Government, industry and other key stakeholders. This would help drive forward nested programmes focusing on specific areas. Such programmes could embrace (or build upon) recent initiatives, including the Jet Zero Taskforce, Future of Flight Industry Group and the UK Space Agency. Each of these would need a clear champion to lead the initiatives. This kind of coherent champion-led programme with aligned reporting structures, delegated budgets and strategies to deliver, are in our view the key to generating the necessary confidence and commitment from all parties.

6.5.12 The focus should include engaging with relevant stakeholders, both within the aviation industry and beyond; developing shared strategy, policy and appropriate regulatory frameworks; identifying emerging issues and trouble-shooting blockages; monitoring and reporting progress; and communicating with the wider public.

Investment challenges

6.5.13 Scaling up new aviation technologies will require substantial investment. The UK Government cannot fund or underwrite the technology development process across the full range of aviation, let alone other technologies; but private sector investors – especially investors in long-term assets – need a clear sense of future policy, direction and – where returns are uncertain and high-risk – assurance on investment frameworks in order to gain long-term confidence.

6.5.14 An overarching approach should be taken by Government that embraces a practical understanding of the different types of funding required at different stages of the technology development cycle, especially in a capital-intensive industry such as aviation. This will ensure incentives are tailored to optimise the value in terms of innovation and attracting investors. The design also needs to provide a clear route map for both capturing and re-investing government equity and re-directing public loan capital as it is repaid whilst ensuring that private investors can understand where their engagement is needed and offers the opportunity for remuneration.

6.5.15 It seems likely that both the already established UK National Wealth Fund and the Green Investment Group could have major roles to play moving forward, as we go beyond the smaller scale of investments that can be offered by UKRI, towards the large-scale financing that is needed to deliver industrialisation and full-scale commercialisation.

6.5.16 To capitalize on economic benefits, the UK should focus on strategies that emphasise the importance of capturing technological patents, supporting product development, attracting investment, and leveraging the advantages provided by new aviation technologies. Any government financial engagement should consider taking equity in projects or technologies it supports so that any dividends or upside in investment value can be captured and recycled for use in the next wave of programmes or projects, and to ensure it has some shareholder influence, e.g. over the location of manufacturing, operations and supply chains, so that the UK – and particularly its regions – are favoured.

Skills Development

6.5.17 The UK has expertise in depth in several important innovation technologies (e.g. propulsion, wings, generic technologies, building specialist production quickly and at scale) and construction and project management process engineering. Addressing resourcing/skills retention concerns is crucial for maintaining this advantage and achieving ambitious goals in the aviation sector.

6.5.18 Looking ahead, skills shortages may be one of the biggest risks faced by the industry and Government in tackling the challenges discussed in this report. As well as traditional aviation and engineering skills, it is clear that the new technologies will demand new skills, e.g. in the growing fields where 'information' and 'engineering' technologies coalesce. Many of these skills, for example in AI and advanced computing, are essentially generic and will be in demand across many industries. Some will be highly specialised. Table 19 summarises some of the skill sets that are likely to be particularly crucial. It is vital, therefore, that the Government and industry develop together an appropriate strategy to address this key dependency.

Table 19: Skills Required to Work in or Regulate Advanced Technology Industries

Skills for Regulating Emerging Technologies	Description
Technical Knowledge of AAM Technologies	Deep understanding of AAM technologies such as electric propulsion systems, VTOL aircraft, and autonomous systems.
Risk Assessment and Safety Expertise	Expertise in risk assessment methodologies and safety management systems specific to AAM operations.
Air Traffic Management	Proficiency in managing complex airspace structures, integrating UAS and autonomous vehicles, and developing new procedures.
Certification and Standards Development	Knowledge and experience in developing certification processes and standards tailored to AAM technologies and operations.
Data Analysis and Monitoring	Skills in analysing large amounts of data from AAM operations, monitoring performance, and ensuring compliance with regulations.
Policy and Regulation Development	Expertise in policy and regulation development to address the unique hurdles and requirements of AAM operations.
Collaboration and Stakeholder Engagement	Ability to collaborate, negotiate, and engage with various stakeholders to develop effective regulations and foster cooperation.
Emerging Technologies and Innovation Awareness	Awareness of emerging technologies, industry trends, and innovative solutions in the AAM sector.

Source: Northpoint Aviation

Communications

6.5.19 Aviation is a high-profile sector, directly impacting the lives of millions of citizens. It can also be highly controversial, most notably when operational failures affect individual customers, but also through its negative associations with noise, pollution and the wider environment. If significant changes are to be introduced successfully it is essential that the public and wider stakeholders, including potential investors, are communicated honestly and effectively. Without this, there is a danger that the industry's 'social license' from the public can come under threat.

6.5.20 Delivering effective communications is a two-way process: engaging with local and national communities, special interests and stakeholders is essential to ensure their concerns are heard, understood and addressed. The better the communications process, the easier it will be to deliver effectively.

Prioritisation, trade-offs and systems thinking

6.5.21 In any large-scale policy endeavour, where ambitions are high, but resources are limited, trade-offs and priority setting become inevitable. Aviation technology programmes are unlikely to escape such tensions.

6.5.22 If we look at future power for aviation for example, it is important to recognise that there will be competition not only from other transport modes but also other industries for batteries (electric vehicle cars and buses for passengers and delivery vehicles for freight), SAF feedstocks (trucks, ships and diesel trains), green hydrogen (coaches, trains and ships) and the renewable energy required to produce them. If productive capacity and the infrastructure linking refineries and airfields remains constrained, then there may need to be interventions about the priority of aviation relative to other sectors; or whether each should be left to compete on the basis of market price and carbon permits.

6.5.23 The technical manifestation of the particular technology, the way in which it is used, the certification, and the production and investment risks inherent in bringing the product or service to market, all affect the business case for investors. At the same time, the complexity of the policy and regulatory tasks needed to bring forward new technologies and the wide range of Whitehall departments and stakeholder interests with an interest in them, all add to the costs, time and ultimately risk involved in bringing forward new initiatives.

6.5.24 If we then look beyond one technology, or even one thematic area of technology, then overseeing and delivering a comprehensive programme of new aviation technologies represents an even bigger and more complex challenge. As identified above, in our roundtable discussions with industry and government stakeholders a notion of a 'systems of systems' was regularly mentioned as the key to the process of managing complexity.

6.5.25 A system of systems (SoS) is the collection of multiple, independent systems (e.g. individual aviation technologies) as part of a larger, more complex system (e.g. aviation in the UK). A system is a group of interacting, interrelated and interdependent components that form a complex and unified whole. These independent and possibly distributed systems pool their resources together, creating a new and more complex system. Individual systems in an SoS work together to provide functionalities and performance that none of the independent systems, or constituent systems, could accomplish on their own.

6.5.26 The goal of an SoS architecture is to get maximum value from a large and complex system. It involves balancing the need for unfettered creativity and competition as a driver of innovation and change, with the need for shared direction, agreed standards and protocols and effective collaboration – in situations where individual companies, working in isolation, are not able to deliver core societal objectives. The SoS approach does not advocate for specific tools, methods or practices: instead, it promotes a new way of thinking for solving complex challenges involving multiple players, technologies, economics and policy goals.

Conclusions

6.5.27 Following the review in the preceding chapter of the way Government is engaging with the industry to develop, promote, scale-up and commercialise emerging aviation technologies, this chapter has attempted to identify where there remain policy areas that must be addressed if these objectives are to be achieved. It is structured around the core technology groupings of environmental sustainability, congestion and customer experience, and new mobilities, that are the focus of this report. Each of these 3 main challenges has its own specific issues and prospects which need to be addressed and the policy responses that are required and the technologies that could help to provide them have been discussed in turn, together with a range of more generic issues.

6.5.28 However, in addition to this, there remains a need for a more holistic overarching approach which draws these challenge specific and generic threads together, provides strategic direction and leadership, and ensures effective communications not only with participants and also the wider public and stakeholders. The models discussed in Chapter 5 and the 'system of systems' concept highlighted above provide important frameworks that would help to facilitate this: while the mission-orientated approach to policy implementation, advocated by Mariana Mazzucato, offers a structured formula for managing its delivery.

7. Conclusions and Recommendations

7.1 Introduction

7.1.1 The focus of this report has been on the technology led challenges and opportunities facing the UK's aviation sector over the next 25 years: how it is responding to these in terms of new technologies, and the problems those solutions face in getting policy support, regulatory certification, investment, finding a market, managing complex risks and becoming commercialised. The experience varies, but for no technology is the passage straightforward.

7.1.2 As we set out at the beginning of this report[148], aviation forms a vital component of the infrastructure that links the modern world together, facilitating face to face global interactions in a way that neither the internet, nor other modes of transport, can achieve quite so holistically or expeditiously. It is also crucial to high-value international logistics operations. It is essential, therefore, that as one of the UK's top export industries[149], as well as a strategically important form of infrastructure[150] that supports many other economic sectors (especially those with a significant international and overseas trade exposure), aviation maintains its strong global market presence[151] and its position as one of the UK's most successful industries.

7.1.3 This report was commissioned to consider the role that emerging technologies can play in addressing the challenges facing aviation. As we have seen, the sheer range of relevant technologies was vast – but between them, they appeared to have the potential to transform the industry. Each technology had its champions and its critics, but the way forward seemed far from clear. Which technologies would be most significant and what challenges would they face in moving from R&D and small-scale prototyping to implementation in the real world at scale and at an affordable cost?

7.1.4 The good news is that, over the course of the review, a coherent picture has begun to emerge. Most important, there is now widespread recognition of what we believe are the core challenges facing the sector. In particular, the need for sustainability; better customer service and operational efficiency through better management of airspace and ground services; and the opening up of the opportunities for new services and new business opportunities offered by new forms of flight.

7.1.5 Of these, the most difficult – and controversial – is the challenge of sustainability. In particular, how to square the circle of meeting the clear desire of growing numbers across the world to fly – illustrated, for instance, by the bounce-back after covid – with the urgent need to constrain and reduce the industry's role in climate change.

148 See above Chapter 1, Section 1.2.0.

149 In 2019 aviation was ranked 7th in terms of UK exports sectors by value at £11.6bn.

150 It is often overlooked that with a mainland stretching over 900 miles from North to South, and with clusters of islands such as the Shetlands, Orkneys, Isles Scilly and Crown Dependencies stretching that distance to closer to 1000 miles, the UK is as long as France, Italy, Germany and some Scandinavian countries, all of which have well developed domestic aviation markets, something which is also essential where cross-water journeys of any significance are required.

151 Third globally, measured by firms and employees.

7.1.6 Some have argued that this cannot be done without serious constraints on the quantum of flight – whether through pricing or other restrictions. Governments have been reluctant to go down this route, partly because of the immediate unpopularity of such a course and partly due to a sense that, unless applied globally, such policies would have limited impact.

7.1.7 There is therefore an emerging consensus, in the industry and beyond, that technology has to play the prime role in meeting this and the other challenges. The jury is still out on just how big a contribution it can make in the limited time available to hit specific climate milestones, and how far other measures will still be needed to meet the country's overarching climate goals. But without very substantial technological change there is little prospect of success. There is no doubt that the faster the industry moves to implement the new technologies the better.

7.1.8 There is also growing consensus about the roles of the main individual technologies. So far as CO_2 is concerned, SAF has the greatest near-term potential, with hydrogen in the longer-term. But electricity, using batteries and hybrid fuel-cells, can also play an important role, albeit in more limited niches. Similar consensus is emerging around the need to use IT, AI and other data- driven technologies to transform the management of airspace (and, increasingly, airports themselves) in ways which will improve both operational efficiency and the experience of customers. And a striking feature of the decade has been the rapid growth of new flying technologies, notably drones but increasingly other vehicles, opening up the prospects of entirely new airborne services and business models.

7.1.9 Finally, we should note that the Government and its predecessors have recognised these challenges and opportunities and have worked hard, in collaboration with the industry, the key regulator (CAA) and others to drive the process forward. The Jet Zero Taskforce, chaired by the Transport Secretary and with strong representation from the industry and other relevant Government Departments, is one example, but as discussed in the report there are several others.

7.2 Challenges and Conclusions

7.2.1 Despite this encouraging picture, however, the review has confirmed that the path ahead remains extremely difficult. For example, much of the focus thus far has been (understandably) on the technology itself: R&D, prototyping, testing, assurance etc. This continues to be essential. However, the biggest challenges now and in the next few years will be less about proving technical viability and more about moving the technology from the 'lab' to implementation at scale and across the industry as a whole. This is a very different challenge, and one in which – at least in other industries – the UK has in the past tended to underperform.

7.2.2 Examples of some of the key issues ahead include:

- How will the new fuels (SAF, hydrogen, green electricity etc) be sourced – and should aviation have any priority over other potential users, of both the feed-source and the green energy itself?
- How will new infrastructure be provided (e.g. to meet the new power requirements, storage and delivery infrastructure at airports)?
- What strategies, levers and incentives will be needed to ensure the necessary investment is available?
- What will be the impact of the changes on the industry's cost base, and how will the costs be met by airports, airlines and end-customers?
- How will the industry source the new skills it needs – e.g., in data, AI etc?

7.2.3 There are also questions of future direction and governance. As a specific example, the new aviation modes such as drones, regional air mobility etc, create new issues around the management of low-level airspace, the need for local infrastructure, the role of local and regional airports, and potential concerns for local communities. These are all issues of crucial importance to local authorities and raise new questions about the role they should play. Comparable issues arise at the international level, where UK and EU airspace needs to be managed coherently and safely across borders.

7.2.4 At a national level we have noted – and welcomed – the project governance structures introduced by the current and previous Government, in collaboration with the industry and others. We particularly welcome the stress on collaborative working, which is essential in such a complex and multi-faceted field.

7.2.5 Looking ahead, however, we see some risks. For example:

- The current arrangements are very issue-specific, with separate governance structures for individual priorities – sustainability, airspace modernisation etc. The advantage is focus, but it makes it relatively difficult to see the 'big picture', identify key cross-cutting dependencies etc.
- Important but generic issues may receive relatively limited attention.
- The focus may be on the relatively immediate (e.g. with titles such as Jet Zero Taskforce, Task & Finish Groups). Again, in some ways this is a strength. But it appears to lack the long-term focus – 20 to 30 years and beyond – which some competitors adopt.
- Communications of plans and progress may be unnecessarily opaque, since they can be scattered across multiple reports.

7.2.6 Our overall conclusion, therefore, is to welcome the real progress made by the industry, regulators and Governments over the last few years; but to recognise that we are still at the very early stages of implementing the transformational changes ahead, some of which – including the most challenging – have intense time pressures. Moving from (in broad terms) the 'R&D' stage to 'industrialisation at scale' is a massive, difficult but urgent challenge – and a key enabler of the Government's wider Missions for both Growth and Climate Change.

7.3 Recommendations

7.3.1 In the light of the above conclusions, we therefore recommend that the Government, in collaboration with the industry, should take the following actions:

7.3.2 **A.** Review, and where appropriate strengthen and reinvigorate, its arrangements (including resources) for driving this agenda forward.

7.3.3 **B.** Adopt a comprehensive strategy for aviation transformation through the deployment of the new technological opportunities, with a 20-30+ year horizon. This should involve clear goals for accelerated decarbonisation, more efficient and customer-friendly operations and the introduction of new modalities opening up new opportunities and services. These goals should be closely integrated with the Government's wider Growth and Climate Change strategies.

7.3.4 **C.** Establish an overarching leadership and governance framework, to set direction, oversee progress and provide accountability and transparency.

7.3.5 **D.** Within this – and building on the current arrangements – embed a range of focussed programmes to give direction and oversight, and trouble-shoot as necessary, to the key individual strands of work. In addition, there should be a strong focus on cross-cutting issues (for example, investment, skills, energy distribution).

7.3.6 **E.** Adopt a strong culture of collaboration. As well as the industry itself, it will be necessary to involve key non-aviation players such as energy, IT and AI innovators, investors, local authorities as well as international partners. In some important areas it will be important to learn from other industries and sectors who may be further ahead in developing new approaches and solutions.

7.3.7 **F.** Beyond continuing development, testing and approval of innovative technologies, place a strong focus on tackling the challenges of commercialisation, industrialisation and implementation at scale. For example: identifying potential financing opportunities and levers to incentivise essential investment; sourcing, and if necessary, prioritising, scarce resources such as SAF and green electricity and hydrogen; planning and developing key infrastructure; and developing the next generation of staff with the skills to deploy the latest technologies.

7.3.8 **G.** Provide transparent engagement and communications with the wider public, giving clarity of policy direction, goals and progress; providing a longer-term policy framework within which the industry, investors and others can plan with confidence; and ensuring appropriate accountability to Parliament and the wider community.

7.3.9 In addition to these core conclusions and recommendations our work also identified several more specific issues which we consider of sufficient importance to merit further review and discussion. A summary of each is provided below.

i. Prioritise the allocation of Sustainable Fuels and Grid Capacity

Aviation will face competition for access to supplies of low carbon fuels such as SAF and green hydrogen from other transport modes and economic sectors seeking to reduce their carbon emissions. There are also likely to be pressures in relation to electrical power and local grid capacity – an issue which is fundamental to supporting the roll-out of Advanced Air Mobility. Both need carefully designed frameworks to ensure the air transport sector has appropriate priority in terms of long-term resource allocation.

ii. Enhance Monitoring and Future Planning

A long-term strategic programme of the kind proposed above will need to be accompanied by robust programme management and monitoring systems. They will need co-ordination between relevant Whitehall departments, their agencies, the industry and investors and will underpin confidence and commitment. An annual report might also be helpful, outlining progress against delivery targets and milestones, and providing an assessment of external pressures and the competition faced by the UK industry that could cause the programme to veer off-track.

iii. Support the collection and publication of Better Data

Our research has revealed a need for better quality data to support decision-making, both at policy level and for individual companies and customers. For example, estimates of the carbon footprint of individual flights are currently derived from aggregated data sources which are then subjected to modelling assumptions. It would be preferable to measure such impacts directly on a flight-by-flight basis. A review of opportunities for more granular, real-time data to support decision making would therefore be helpful.

iv. Recognise the role of Local Authorities and resource their engagement

As well as certifying new technologies such as drones, the CAA currently takes the lead in approving individual drone operations, especially for BVLOS missions through the new SORA process[152]. Our discussions raise the question whether, with the likely expansion of such services, local and regional authorities should now play a larger role, such as taking the lead in planning and decision-making on drone and e-VTOL infrastructure. This might help build local public confidence, embed novel services in broader local economic and policy planning, and encourage wider access, e.g. in rural or remote areas or those served by smaller airports.

152 SORA is a Specific Operations Risk Assessment, which is a way to classify the risk posed by a UAS operation and then identify mitigations and safety objectives to counter those risks.

v. Encourage the adoption of Generic Digital Technologies in Aviation

This report has highlighted the role that AI, machine learning, quantum computing and robotics, could play in helping to meet some of the strategic challenges. However, while there is evidence that key sectors of the industry are already looking to adopt these technologies, it is important that they broaden this engagement into other areas of digital innovation and robotics, whilst ensuring that process is safe, efficient and maximizes benefits for the industry and consumers.

7.3.10 Hence our final recommendation is that each of these issues need further consideration and evaluation as part of any follow-up work arising from the publication of this report.

Glossary of Abbreviations

AAM	Advanced Air Mobility
AAPG	All Party Parliamentary Group
ACI	Airports Council International
ACOG	Airspace Change Organising Group
ATCO	Air Traffic Controller
ADS-B	Automatic Dependent Surveillance – Broadcast
AI	Artificial Intelligence
AIA	Aviation Impact Accelerator (University of Cambridge)
ANC	Active Noise Control
ANS	Air Navigation Services
ANSP	Air Navigation Service Providers
AOA	Air Operations Area
APU	Auxiliary Power Unit
ATAG	Air Transport Action Group
ATC	Air traffic control
ATI	Aerospace Technology Institute
ATM	Air Traffic Management
AvGas	Aviation Gasoline
AvTech	Aviation Technology
BEIS	Department for Business, Energy and Industrial Strategy (UK)
BSI	British Standards Institute
BusAv	Business Aviation
BVLOS	Beyond Visual Line of Sight
BWB	Blended Wing Body
c-VTOL	Conventional Vertical Take-off and Landing aircraft
CAA	Civil Aviation Authority
CAGR	Compound Annual Growth Rate
CCC	Climate Change Committee
CDA	Continuous Descent Approach
CDM	Collaborative Decision-Making
DARPA	Defence Advanced Research Projects Agency
DBT	Department for Business and Trade (UK)

DfT	Department for Transport (UK)
DLT	Distributed Ledger Technology
DMH	Downtown Manhattan Heliport
DSIT	The Department for Science, Innovation and Technology (UK)
e-CTOL	Electric-Conventional take-off and landing
e-VTOL	Electric-Vertical take-off and landing
EASA	European Union Aviation Safety Agency
ETOPS	Extended-range Twin-Engine Operations Performance Standards
ETS	Emissions Trading Scheme
FAA	Federal Aviation Administration
FFC	Future Flight Challenge
FFIG	Future of Flight Industry Group
FoF	Future of Flight
FTS	Fischer-Tropsch Synthesis
GA	General Aviation
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GNSS	Global Navigation Satellite System
GOLIAT	Ground Operations of Liquid hydrogen AircrafT
GPS	Global Positioning Systems
GPU	Ground Power Unit
GVA	Gross Value Added
HAPS	High-Altitude Platform Station
HAV	High-Altitude Vehicle
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICCAIA	International Coordinating Council of Aerospace Industries Associations
IOSM	In-Orbit Servicing and Manufacturing
IP	Intellectual Property
IT	Information Technology
ITC	Independent Transport Commission
LA	Local Authority
LEO	Low Earth Orbit
LGA	Local Government Association
MaaS	Mobility as a Service

NASA	National Aeronautics and Space Administration.
NATS	National Air Traffic Services
NGO	Non-Governmental Organization
OEM	Original Equipment Manufacturer
P-RNAV	Precision Area Navigation
R-NAV	Area Navigation
R&D	Research and Development
RAM	Regional Air Mobility
RFF	Resources for the Future
RIO	Regulatory Innovation Office (UK)
RTC	Remote Tower Centre
RVT	Remote Virtual Towers
SAF	Sustainable (or synthetic) Aviation Fuel
SASIG	Strategic Aviation Special Interest Group
SBAS	Space-Based Augmentation System
SORA	Specific Operations Risk Assessment
SOS	System of Systems
STOL	Short Take-Off and Landing
TBO	Trajectory-based Operations
TIC	Titanium Carbide
TMA	Terminal Manoeuvring Area
TSA	Transportation Security Administration
UAE	United Arab Emirates
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UHBR	Ultra-High Bypass Ratio
UKADS	UK Airspace Design Service
UKRI	UK Research and Innovation
UKSA	UK Space Agency
UTM	Unmanned Aircraft System Traffic Management
UV-C	Ultraviolet Light (180-280 nanometre wavelengths)
VR	Virtual Reality
VTOL	Vertical Take-Off and Landing

Appendices

Due to limitations of space in this report, the authors have created a set of Appendices with further information on various aspects of this research for those interested. These include:

Appendix A:	Terms of Reference for the research underpinning this report
Appendix B:	Further details of the Research Methodology
Appendix C:	Further exploration of Group D technologies
Appendix D:	Possible 'Mission Statement' for the UK's emerging aviation technologies sector

These Appendices can be accessed and viewed online at the ITC's website:

www.theitc.org.uk/our-research/research-reports-2

Author Profile

Chris Cain was educated at the Universities of Oxford and Newcastle, is a professional urban and transport planner by training and since 2022 has been the Managing Director of Northpoint Aviation Services. His 30 years of senior transport experience includes having been the Project Director for Newquay Airport at Cornwall Council, Regional Airports Manager at the UK Department for Transport, Programme Manager for East London River Crossings at the Government Office for London and a Project Manager on the Channel Tunnel Rail Bill. He also provides insights to the Strategic Aviation Special Interest Group (SASIG) and the Regional and Business Airport (RABA) Group and is a member of the Air Transport Research Society and Institute of Economic Development. Chris's extensive practical experience is underpinned by sound analytical and business planning skills, a facility for managing large and controversial stakeholder exercises, developing sound working relationships with politicians at all levels, and an ability to execute policy initiatives that have captured material benefits for both the public and private sectors.

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November 2025

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