INSIGHT

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Introduction

This INSIGHT explores the path towards autonomy in civil air transport, focusing on the technologies associated with air vehicles, airspace management and ground operations. Potential challenges and barriers to achieving full autonomy are considered, such as public acceptance, certification and regulatory issues. A high-level technology roadmap is included, which will guide the ATI in the support of relevant R&T projects.

15 *The Journey Towards Autonomy in Civil Aerospace*

EXECUTIVE SUMMARY

An autonomous air transport system has the potential to deliver higher levels of safety and productivity than today's human controlled system. It can transform the way we use flight to deliver services, enabling sub-regional and urban air transport, the routine use of drones to deliver cargo, and a broad range of services including blue light, survey, maintenance and construction. It will require substantial changes to air vehicles, air traffic control approaches and supporting ground infrastructure and operations.

Autonomous systems decide for themselves, without human intervention, how they achieve a mission – they will continually respond to the changing state of the vehicle and its surrounding environment; they learn and adapt their future behaviour accordingly. This is different from automated systems where the outcome and the series of operations to achieve it are pre-determined and may need human intervention.

This INSIGHT outlines a path to fully autonomous flight and operations for civil air transport. This path requires the development and combination of a range of autonomous and highly automated systems technologies. It considers the views of industry, academia and other aviation interest groups on autonomy and the challenges in moving forward. Although there are broader issues around public acceptance and certification that need to be addressed, this document concentrates on the aircraft, air traffic management (ATM) and ground operations systems that will be required for autonomous flight, captured in a high level technology roadmap. The roadmap will guide the ATI in supporting the acceleration of the development and exploitation of these technologies in the UK.

CONCEPT OF OPERATIONS FOR AN AUTONOMOUS FLIGHT

Figure 1 displays a concept of operations (CONOPS) of an autonomous flight from a departure airfield to a destination airfield. The flight mission starts with the flight planning process which overall may be similar, but the system may need to autonomously gather information on weather, route, runway, take-off weight and fuel as well as scheduled arrival times etc. Once installed into the onboard systems, which will acknowledge it to the monitoring presence, the autonomous operation will start with push-back, taxi to the departure runway, take-off, climb, enroute to top of descent, descent to position for an approach to a destination airfield, conduct an approach, land and taxi back to the gate.

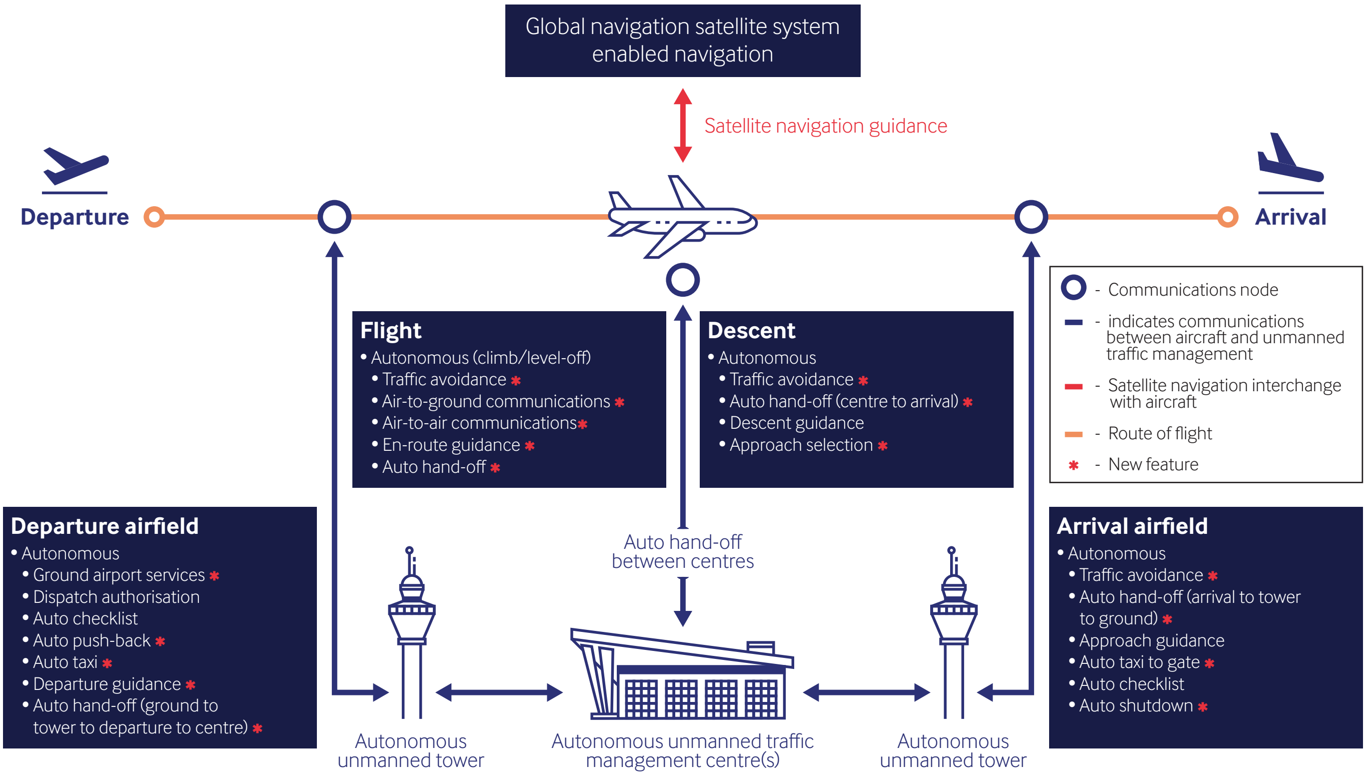

Figure 1 - A conceptual visualisation of an autonomous flight

ASPECTS OF AN AUTONOMOUS AIR TRANSPORT SYSTEM

Five aspects of an autonomous air transport system are shown schematically in Figure 2. These aspects are discussed in subsequent sub-sections:

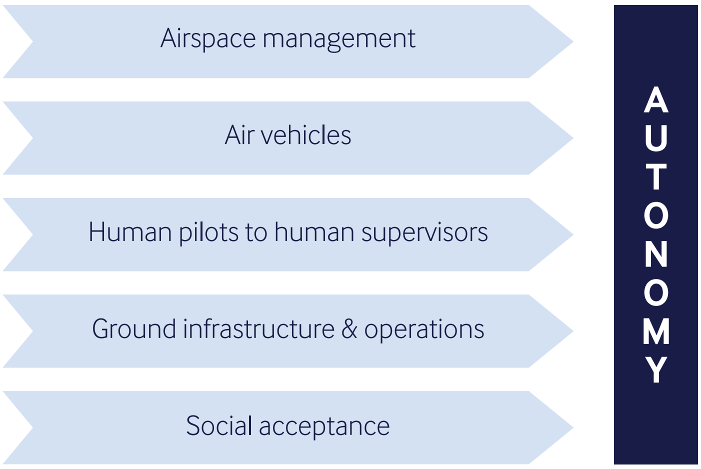

Figure 2 - Five aspects of an autonomous air transport system

Airspace management

Airspace management must evolve into unmanned aircraft system traffic management (UTM) to accommodate autonomy. It will have to be adaptable to cater for changing mixtures of non-autonomous and autonomous air vehicles co-existing in the same airspace. Some level of autonomy will be required within the air traffic management system to cope with the variety of air vehicles and the potential to vastly expand the number of vehicles operating in controlled airspace. Airspace control will be extended to incorporate altitudes between ground level and 2000ft to allow full utilisation of the lower airspace. It is inevitable that there will be a transition from conventional approaches to newer ones and there will be challenges in managing different approaches through the transition.

Air vehicles

In an autonomous air vehicle, the autonomous system must fulfil all the functions of a conventional aircrew: navigation and guidance, flight control, engine control, management of flight, vehicle, health, fuel and energy, communications, ground manoeuvres and handling. The vehicle will need to continually inform the air traffic control system and other air users of its location and course. The vehicle will need to sustain situational awareness in the air and on the ground, and take evasive action to avoid conflict with airborne and ground hazards. It will need to manage and recover from emergency situations.

There are options regarding the cockpit for autonomous aircraft. The cockpit with its controls and displays could be considered redundant as no human intervention would be required. Therefore, any human interface on the aircraft should be designed for the needs of the human on the ground who will be monitoring the air vehicle. Alternatively, if a suitably trained cabin crew member is required to assume control in an emergency, a cockpit would be required to have suitable controls and displays that would allow for quick transition from fully autonomous to semi-autonomous flight.

Potential considerations needed for overall awareness for an autonomous air vehicle are further described in Figure 3.

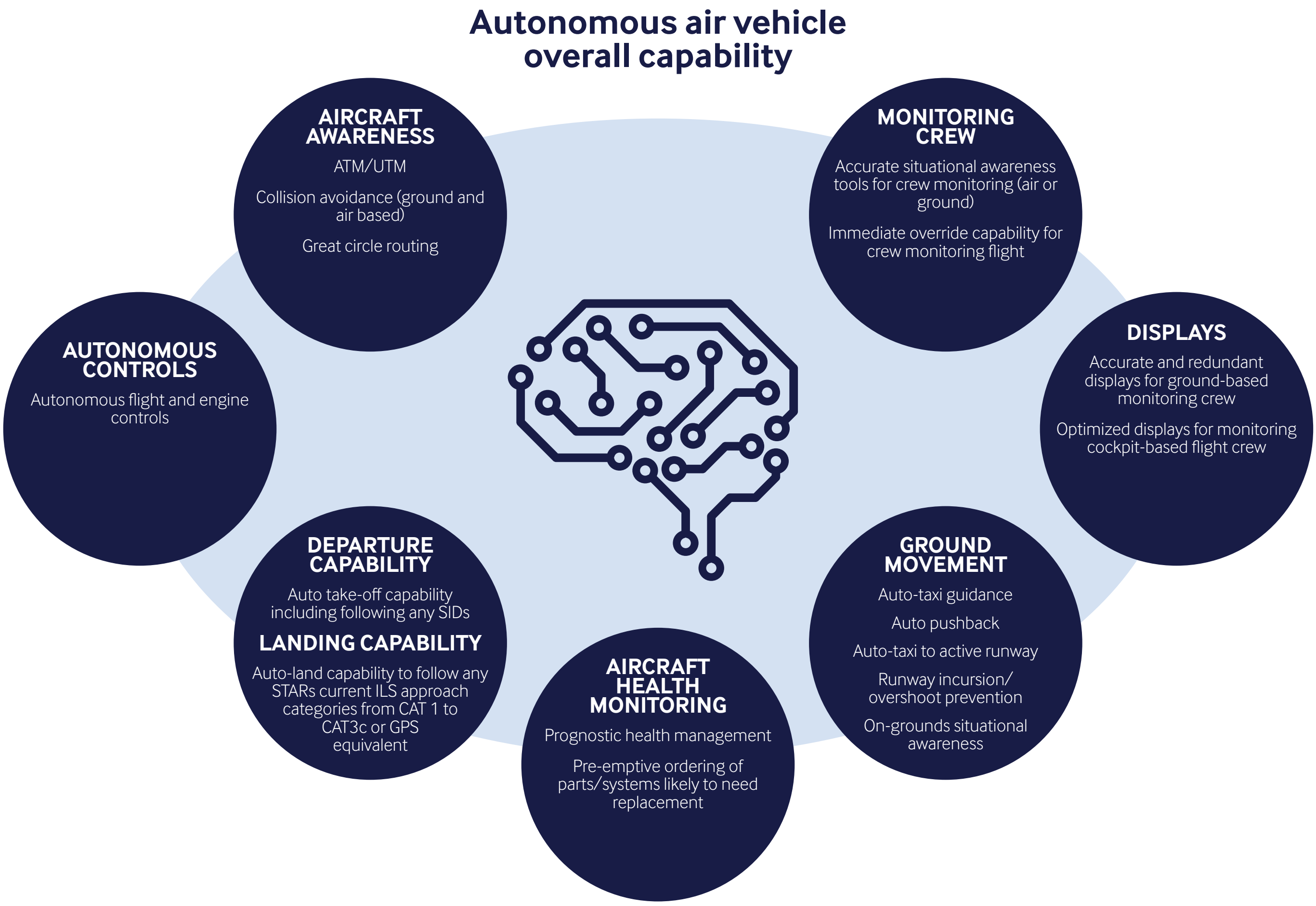

Figure 3 - Elements needed for overall capability for an autonomous air vehicle

Human pilots to human supervisors

For civil passenger and cargo aircraft, it is accepted that there will be a transition from today's two pilot cockpit through to single pilot operations and eventually fully autonomous systems with no requirements for a pilot. In two pilot flight operations today, the pilots work together to check each other's actions and manage high workload situations. In the extreme, should one of the pilots become incapacitated, the remaining pilot is capable of safely flying the aircraft. In single pilot operations there needs to be alternative means to back up the pilot and this could be where autonomy finds its first application on passenger aircraft. The ATI has published an INSIGHT paper with a more detailed examination of single pilot operations[1]. There are compelling reasons to move towards single pilot operation. The potential future shortage of commercial pilots is causing concern, particularly as the number of commercial aircraft continues to increase. This could be exacerbated by new urban and sub-regional markets for electrically propelled air vehicles. These vehicles will be smaller, probably less than 20 seats and therefore the crew costs will be a much higher proportion of the overall operational costs. It is likely that single pilot operations are proven in non-passenger carrying cargo operations before passenger aircraft. The next step would be to introduce fully autonomous cargo aircraft. Public acceptance will be a key issue.

It is not clear whether autonomous air vehicles will need to be monitored by a human either sitting in the aircraft or on the ground. The conclusion will be determined by the social acceptance of full autonomy versus human supervised autonomy.

Ground infrastructure and operations

Future ground infrastructure and aircraft handling will need to facilitate the operation of autonomous air vehicles. These aspects include:

- Air traffic control infrastructure, including radar and communications systems
- Control of autonomous and human piloted air vehicle movements on the ground
- Control and operation of ground vehicles
- Coupling, uncoupling, unloading and loading of air vehicles
- Coordination of humans and machines

Some or all of these aspects could be automated or autonomous (unmanned ground airport services or UGAS) to facilitate improved safety and efficiency.

Social acceptance

Public acceptance is a key issue in the path towards single pilot and autonomous operations, particularly for passenger aircraft, with the key consideration for the travelling public being "am I happy to fly on a plane with no pilots?". This is discussed further later in this paper.

THE AUTONOMOUS VEHICLE VISION

The vision for the autonomous air vehicle is a vehicle able to carry out a mission from start to finish, self-determining and self-learning with the assistance of autonomous or semi-autonomous UTM and UGAS, without human intervention apart from definition of the flight objectives. The route to this vision is through increasingly capable, safe, and secure technology replacing the human element in the cockpit for previously manned operations; a confident public and media perception; and robust regulatory and certification processes. Autonomous systems will be critical in reducing aircrew workload and enabling higher capacity and even safer air transport systems. In addition, fully autonomous vehicles offer cost advantages and will ultimately open new applications. The ATI is focusing on autonomous technologies that offer the broadest benefits in civil aerospace. The Institute is supporting cross-sector knowledge transfer on the autonomous transport agenda through engagement with the Connected Places Catapult (CPC).

[1] ATI Single Pilot Commercial Aircraft Operations INSIGHT

TRANSITION TO AUTONOMY

Autonomy will not happen overnight; there will be a transition period where autonomous air vehicles operate in the same airspace as human controlled ones. In fact, airspace may never be fully occupied by autonomous vehicles. For passenger air vehicles, there will inevitably be a transition through single pilot operations before full autonomy. Figure 4 shows the progression from a multi-crew operation through single pilot operations and finally to autonomous flight with a monitoring crew.

For commercial flights today, unless the aircraft is cleared for single pilot IFR operations, the crew complement consists of two pilots. One of the pilots for a given leg will be the Pilot-Flying (PF) and the other pilot will be the Pilot Not-Flying (PNF). The PF's task is to fly/monitor the aircraft using automation as prescribed by the airline standard operating procedures (SOPs). The PNF monitors the PF, implements changes to frequency, altitude and heading as appropriate, and conducts appropriate checklists at the appropriate stages of the flight. The PNF's tasks include challenging the PF if the aircraft configuration is something other than expected, recognising and dealing with emergencies in a collaborative manner, and all air/ground communications as needed. In single pilot operations, the PF is also responsible for the PNF's duties, but the category of aircraft authorised for such operations is limited. Incapacitation is the main threat to unmonitored single pilot operations, which to some degree is eliminated in fully autonomous operations. Moving to full autonomy from single pilot operations is likely to be an easier transition for smaller commercial aircraft and cargo carrying aircraft. This will be the proving ground for safety and acceptability prior to introducing autonomy to larger passenger carrying aircraft.

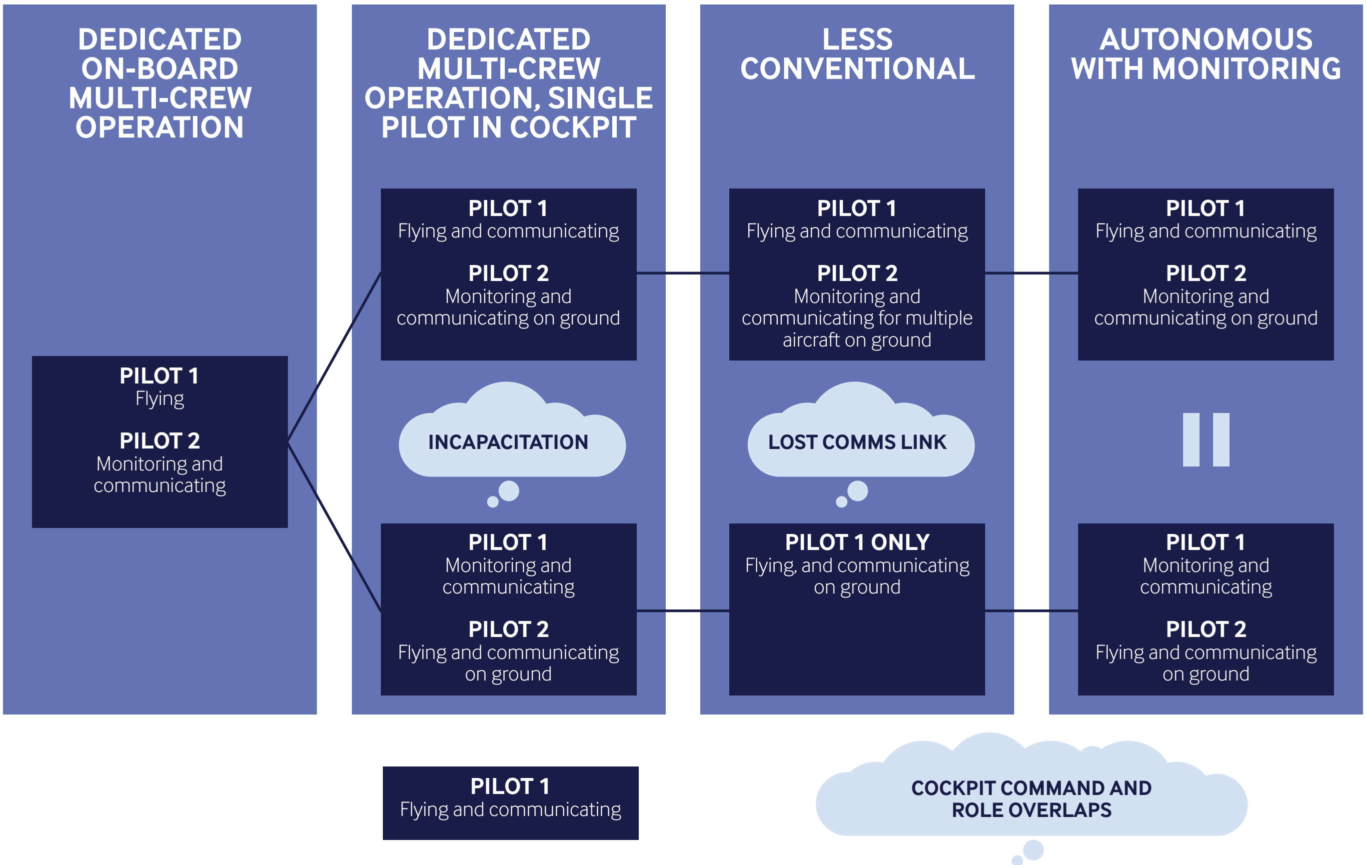

Figure 4 - Transition to autonomous operations

From the operational environment perspective, the transition to autonomy will see a mix of traffic that is autonomous with traffic that is automated, with pilots in control. The transition is likely to be relatively slow with risks attached. This transition will need to be thought out carefully and planned meticulously to prevent incidents that jeopardise the move towards complete autonomy of air traffic.

CHALLENGES TO INTRODUCING AUTONOMY

There are three challenges to introducing autonomy: societal acceptance, technology, and safety and security. These are shown in Figure 5, along with an indication of how they can be overcome.

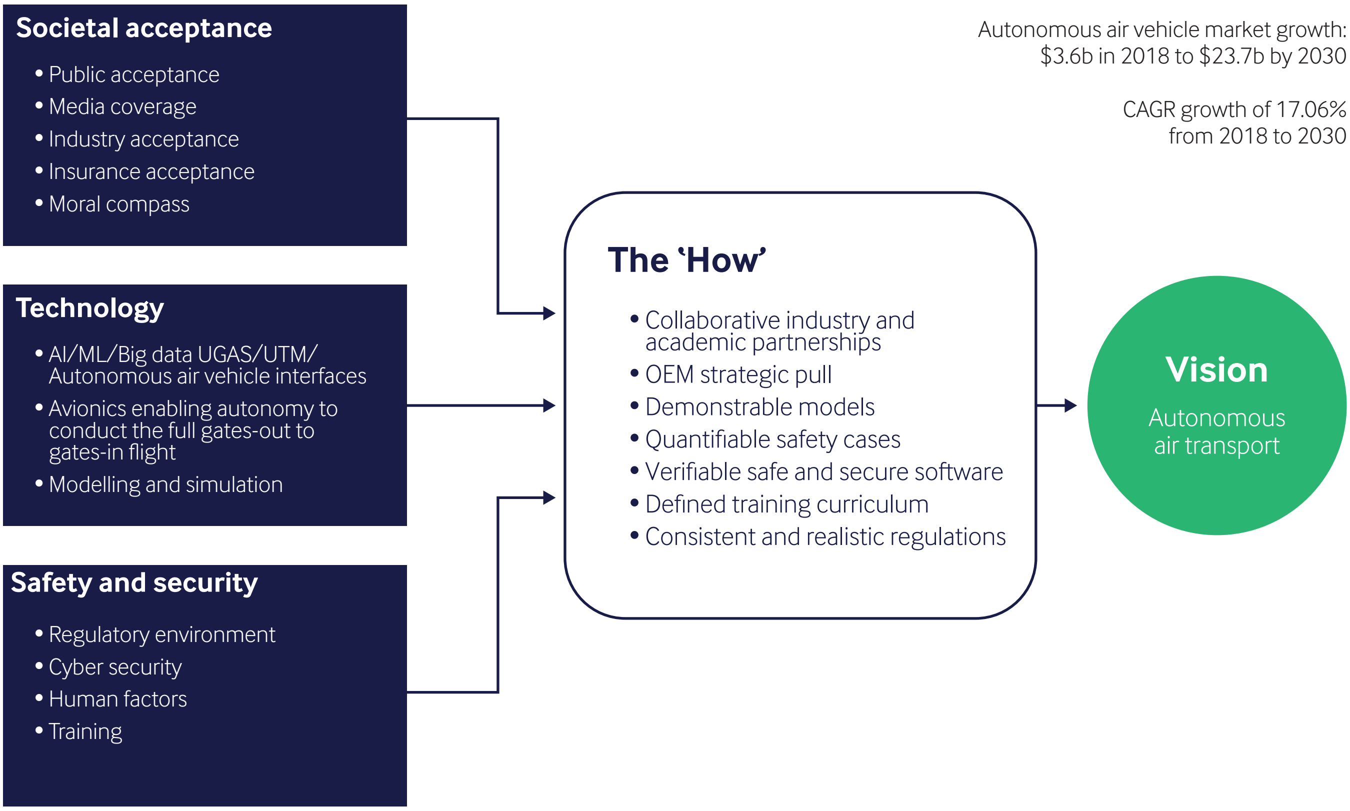

Figure 5 - Challenges for the introduction of autonomy into civil air transport

These challenges are explored in the following sections.

Societal acceptance

Public acceptance

One of the biggest challenges to the introduction of autonomous air vehicles will be public acceptance. Referring to pilotless commercial aircraft, John Hansman, professor of aeronautics and astronautics at the Massachusetts Institute of Technology commented: "The issue has never been 'Could you automate an airplane and fly it autonomously?' The issue is 'Could you put paying customers in the back of that airplane?'". Passengers are comforted by seeing two highly skilled and trained human pilots at the controls of a very complex piece of machinery. Another challenge is the ethics of the decision-making of the system. Any decision made by the system will have consequences, both good and bad. This would then lead to culpability and liability issues. Industry must work together with certification and regulatory authorities to test potential scenarios and issues proactively rather than reactively.

Media acceptance

The media will play a key role in influencing public acceptance. Industry and the authorities will need to convince the media by keeping them aware of the progress being made to the point where both the media and subsequently the travelling public are reassured sufficiently to embrace the technology.

Air transport industry acceptance

Testing and validation of autonomous systems involves understanding, and confidence in, what the autonomous system has done and what it will do next based on what is considered normal for that system in each context. Ultimately, there needs to be a level of trust established. Industry is convinced that autonomy will come at some point in future air vehicles. The role of the human will change from controlling to monitoring. Industry recognises there is a large commercial risk involved with pursuing autonomy because the path to autonomous air vehicles is an uncertain one, with the route to certification being critical.

Technology

Aerospace systems are heavily dependent on software and related hardware technologies. Some 80% of typical aircraft functions today are dependent on software-based systems, as shown in Figure 6.

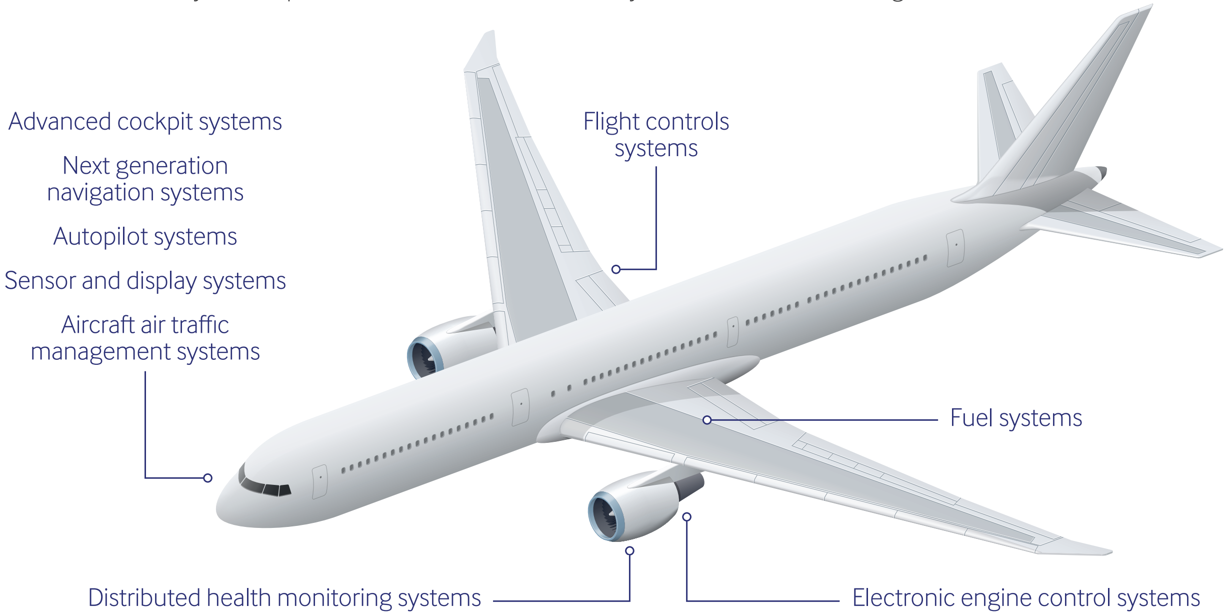

Figure 6 - Software-enabled aircraft systems and software systems

Centre to the technology needed for a fully autonomous air vehicle is the development of 'intelligence'. We expect autonomous machines to show intelligence in a similar way to humans, including:

- Decision-making
- Knowledge
- Ability to communicate
- Ability to obtain more information/knowledge
- Ability to learn
- Ability to make reasoned arguments and decisions
- Comprehend and understand the concept of accountability for actions
- Have a level of awareness of the world and the environment
- Ability to make decisions from limited knowledge and extrapolate from it
- Cognitive capability

To form an intelligent position on a situation that a vehicle might find itself in, relevant information needs to be gathered and a judgement call made on the validity of that information with minimal bias. Prior knowledge and experience gained through access to the experience and knowledge of others and through self-learning are key to this.

Artificial intelligence (AI)

AI is the theory and development of computer systems able to perform tasks normally requiring human intelligence such as visual perception, speech recognition, decision-making, and translation between languages. For fully autonomous air vehicles, the air vehicle needs to be able to learn. An initial system would be 'taught' using existing data and models. Once the system is operational it will acquire new data and use that to modify its models of the world and hence its behaviour. Through the life of the systems, there needs to be ready access to information to aid decision-making. For decision-making, the transition to AI could be classified as follows:

A. Sensing (acquisition of rules)
B. Comms (using information – learning)
C. Access to data
D. Reasoning ability (self-correction)
E. Experience and ability to learn

It may be the case that initial systems could learn during operation, but they are more likely to learn offline.

The substantial progress and the reduced cost of computing power and memory, together with the availability of big data, connected devices and advanced algorithm development have resulted in the many successes of AI. However, a recent report by Scientific American[2] makes the case that although AI has breached a new area of application which either matches or exceeds human proficiency down to task level, there is a large gap between expectations and the current reality for most organisations. A poll reported in the Scientific American[3] found only 5% of executives, out of the 3000 asked, engage in substantial AI-centric activities and 20% use any AI at all. A large percentage, 85%, expect AI to result in a competitive advantage. Clearly there is a gap in the belief versus the use and the expectations far outweigh the reality. Furthermore, talent shortages and unequal access to data engineers and AI experts also lead to gaps in progress of the subject.

Machine learning (ML)

ML is a subset of AI in which computer systems learn from observational data and real-world interactions in order to create a model of the real world. The basis for ML is to create software algorithms which receive data as an input to predict the output, while updating outputs as new data which then becomes available using statistical analysis. The goal for ML is to become more accurate at predicting outcomes without being explicitly programmed.

Application of AI/ML

Current approaches to autonomous systems combine AI and ML. There are two schools of thought in AI and ML:

A. Capture learning: The concept of learning realised and then captured to be tried out either immediately or later. This is considered the lower risk option as it is a more controlled way of establishing and building up a learning profile.

B. On the fly learning: This concept is based on learn as it goes, where the system accumulates data, experiences, learning and reasoning during operations. The method is considered to be the most beneficial way in achieving AI/ML objectives, but it is higher risk.

Big data

Autonomous air vehicles will generate very large amounts of data:

A. By the air vehicle itself for guidance, flight control applications, communications and vehicle health monitoring

B. By the air vehicle and ground systems for large, real time communications and coordination between air and UTM for flight in and out of controlled airspace, situational awareness, collision avoidance and ground operations.

Big data is extremely large data sets that may be analysed computationally to reveal patterns, trends, and associations, especially relating to human behaviour and interactions. Care needs to be taken to ensure the data is uncorrupted, uncompromised and valid before analysis.

Modelling and simulation

A study conducted in 2014[4] suggests that for autonomous air vehicles to be used for civil applications, regulatory certification approval must be gained. One such way would be through a proof-of-concept approach to the generation of certification evidence for autonomous flight based on a combination of formal verification and flight simulation, including modelling. Different verification methods provide a higher level of confidence in providing a means to generating evidence for certification of autonomous unmanned, and potentially manned aircraft. Higher levels of assurance for the safety of autonomous aircraft can potentially be gained. Key evidence would be obtained by:

i. Outputs of the model checker
ii. Higher fidelity environment model checking
iii. Model comparison and refinement based on flight simulation.

[2] https://blogs.scientificamerican.com/observations/artificial-intelligence-the-gap-between-promise-and-practice/
[3] https://blogs.scientificamerican.com/observations/artificial-intelligence-the-gap-between-promise-and-practice/
[4] https://cgi.csc.liv.ac.uk/~matt/pubs/jais2014.pdf

Quantum technologies

Quantum technologies may offer benefits to future autonomous systems. Single photon detector-based sensors, available today, offer the potential to see in degraded visual environmental conditions, and are very applicable to improving situational awareness. The key challenge is cost, with single photon detector systems currently being very expensive. Quantum security for autonomous systems, e.g. quantum key distribution (QKD), is likely to be a realistic prospect soon. QKD systems exist today and they may provide a practicable solution for secure aircraft systems in the relatively near term.

Safety and security

Certification and regulatory authorities are likely to face a challenge to set standards that establish fully autonomous air vehicles are safer for passenger travel than current highly automated air vehicles.

Regulatory environment

The consensus is that regulations and guidance are not well-suited[5] to the type of software used in autonomous systems (e.g. AI, ML etc). The challenge will be the development of systems and software verification processes that provide assurance, along with convincing arguments as to their robustness. Current processes for automated systems and software are built on their deterministic nature. Autonomous systems are non-deterministic and so cannot be certified using existing processes. ICAO have recently updated their Doc 7300 for the inclusion of UAS regulation[6]. It recognises that UAS operations involve stakeholders familiar with aviation as well as those who are not, and includes these stakeholders from the beginning when developing the UAS regulations. Their early involvement will ensure that the regulations appropriately address the needs of these groups while also serving to educate them on expectations and what is feasible. The RAND corporation has produced a paper[7] which summarises the rapidly changing body of commercial drone regulations worldwide through literature review and discussions with subject matter experts and also highlights the primary obstacles to delivery drone use internationally. For the autonomous car industry, the DfT produced a summary report and action plan document[8] in 2015 in which the UK Government has set out clear next steps showing how it will continue to ensure the regulatory and legislative framework is there to support the further development and mass production of automated vehicle technologies.

In the automotive world, autonomous vehicle levels have already been defined, with Level 1 being the most basic and Level 5 being the most advanced. The same levels could be used for autonomous air vehicles (see Figure 7).

Pilot Authority Control of Tasks (PACT)

	PACT level	Computer autonomy	Levels of human machine interface (modified from Taylor, 2001)
Human monitors	**5b** *Fully autonomous*	Computer monitored by pilot	Computer does everything autonomously
	5a		Computer chooses action, performs it and informs human
	4b *Direct support*	Computer backed up by pilot	Computer chooses action and performs it unless human disapproves
	4a		Computer chooses action and performs it if human approves
	3 *In support*	Pilot backed up by computer	Computer suggests options and proposes one of them
	2 *Advisory*	Pilot assisted by computer	Computer suggests options to human
	1 *At call*	Pilot assisted by computer only when required	Human asks computer to suggest options and human selects
Human action	**0** *Command*	Pilot	Whole task done by human except for actual operation

Increasing autonomy, integrity, in service date

Figure 7 - Transition model from manned to un-manned (fully autonomous) flight

[5]Ashmore, R, Lennon, E (2017) Progress Towards the Assurance of Non-Traditional Software. In Developments in System Safety Engineering, ISBN 978-1540796288.
[6]https://www.icao.int/safety/UA/UASToolkit/Pages/Narrative-Regulation.aspx
[7]https://www.rand.org/content/dam/rand/pubs/research_reports/RR1700/RR1718z3/RAND_RR1718z3.pdf
[8]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/401562/pathway-driverless-cars-summary.pdf

Cyber security

The Department for Transport (DfT) has produced a guideline book[9] which outlines the challenges the UK's aviation industry faces from the cyber threat. The guideline aims to provide a clear path to 2021/2022. It recognises that the cyber threat is not a uniform and constant entity, but rather one that will grow and continue to adapt and therefore will require continuous monitoring and mitigation. The guideline also recognises the necessity for collaboration and support to keep the aviation transport sector safe. The four-part government strategy is as follows:

A. Understand the cyber risks
B. Manage the cyber risks
C. Respond to and remove cyber events
D. Promote the building of cyber capability – this is crucial for the move to fully autonomous vehicles

Human factors

The human factors strategy for single pilot operations is to design the avionics and pilot interface in the cockpit to present a single pilot operator with a manageable workload, which will be considerably lower than for a conventional two pilot cockpit. Although this may not appear to be a concern for fully autonomous air vehicles, it remains so if the consensus is that autonomous air vehicles need to be monitored by a human either sitting in the aircraft or on the ground. The route to full autonomy is a step beyond single pilot operations, filling in the technological and infrastructure 'gaps'.

Training

Operator training for autonomous environment operations will need to change as the traditional roles of the human changes. Whether the training requirements are significant remains to be seen. However, the transition from partially controlling an aircraft to simply monitoring an aircraft, or several aircraft, and being ready to assume control could be significant for pilots. The primary training challenges are likely to be as follows:

- Ground services staff training for:
- Baggage handling
- Preparing the aircraft for flight
- Authorising the flight
- Sign-off for the flight
- Air traffic communications with an autonomous air vehicle.
- Flight training changes for ground-based or on-board pilots is likely to be minimal from the perspective of actual flying of the aircraft. However, there are likely to be significant changes to the systems and procedures training required for the additional pieces of equipment necessary for full autonomy. This will include training for operating the aircraft on the ground.

Procedures for operating autonomous air vehicles will change and therefore will directly affect the training of the staff involved with operating autonomous vehicles. These procedures will need revisiting and therefore the training materials associated with them.

MARKET OPPORTUNITY

Autonomy in commercial aviation will disrupt current business models by dramatically changing operating economics. The move to single pilot operations alone could save the industry $60bn annually, and pushing further to fully autonomous systems could save up to $110bn. There are multiple other operational cost savings and efficiencies that autonomy enables and increases its economic proposition, such as a 6% fuel burn through optimised speed and altitude. It is challenging to quantify the market potential for autonomy as its benefits will weave through the entire air transport sector and beyond. It will include both hardware and software products, as well as services across air and ground communications, and maintenance, repair and operations organisations (MRO).

Autonomy will further permeate and influence the market by increasing operational capacity and further improving safety. Safety improvements could save millions in insurance costs and settlements. Cockpits could be shrunk and potentially eliminated, cutting aircraft cost and increasing payload. Airlines may enjoy greater scheduling flexibility as the limits imposed by human pilot flight-hour regulations would not be required.

[9]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/726561/aviation-cyber-security-strategy.pdf
[10]https://www.oliverwyman.com/our-expertise/insights/2017/oct/airlines-aim-for-autonomous-flight.html

Airport delays and disruption in the USA alone can cost an airline over $1bn a year. A significant portion of this could be solved by eased congestion through smart autonomous traffic management technology.

The global commercial[11] avionics market is projected to grow from $68.5bn in 2019 to $86.9bn by 2024, at a CAGR of 4.86% during the forecast period. Avionics will evolve to include autonomy enabling software and hardware.

The unmanned traffic management market is estimated to be $538.2m in 2018 and is projected to reach $1.96bn by 2025, at a CAGR of 20.28% from 2018 to 2025.

The UAV market is estimated at $19.3bn in 2019 and is projected to reach $45.8bn by 2025, at a CAGR of 15.5% from 2019 to 2025. The rise in the procurement of military UAVs by defence forces worldwide is one of the most significant factors projected to drive the growth of the UAV market. The increasing use of UAVs in various commercial applications such as monitoring, surveying and mapping, precision agriculture, aerial remote sensing, and product delivery is also contributing to the growth of the UAV market.[12]

Autonomy is critical to unlock the true potential of disruptive emerging markets such as urban air mobility (UAM) and UAS for goods and air-delivered services. Without autonomous systems, these solutions will remain too expensive and too high a risk to become ubiquitous and unlock the true economic benefits. The ATI predicts that the worldwide UAM market could be upwards of $360bn through to 2039.

The autonomous air vehicle market is projected to grow to $23.7bn and at a CAGR of 17.06% to 2030[13]. The growth is based upon the following three factors:

A. Increased cost savings
B. Reduction in human error due to increased autonomy
C. Advancements in AI

North America accounted for the largest share of the autonomous air vehicle market in 2018, but the rest of the world comprising of the Middle East, Africa, and Latin America, is expected to be the fastest-growing market going forwards.

Table 1 shows the categorisation of vehicles, unmanned traffic management and ground support services that are needed to operate the majority of commercial autonomous flight operations. Autonomy can be applied to any platform and therefore is platform agnostic.

Autonomous air vehicle (Payload)	**Unmanned Traffic Management (UTM)**	**Ground airport services**
Commercial (UAV) goods	Flow management (encompasses all below)	Ticketing
Urban air transport (1-10 pax)	Urban environment	Baggage handling
Sub-regional (5-19 pax)	Local environment	Aircraft taxi support
Regional (20-120 pax)	Domestic	Aircraft support services (fuel, O_2, catering etc.)
Large commercial (>120 pax)	International	Dispatch & maintenance
UK Stakeholders		
Industry Regulator Certification authority Airlines Academia Airlines and air travel representatives International Civil Aviation Organisation (ICAO)	UK air navigation provider ICAO Airline and air travel representatives Regulator Certification authority Industry Academia	Airlines Regulator Certification authority Airport authority Academia
Recommendations		
Encourage and invite new ATI/Future Flight Challenge (FFC) projects including those which benefit technology that aids the move towards autonomy.	Encourage and invite new FFC projects including those which benefit technology that aids the move towards autonomy. Future ATI studies into autonomous UTM for all categories of air travel.	Future ATI studies into autonomous ground airport services that supports autonomous air vehicles.

Table 1 - Aviation considerations for autonomy

[11]https://www.marketsandmarkets.com/Market-Reports/commercial-avionic-system-market-138098845.html?gclid=CjwKCAiAsIDxBRAsEiwAV76N82e_zJZflL5wQldg3IeCwIcIEMehHLr-qCRKktKxtFsuhchimkgHOBoC3_4QAvD_BwE

[12]https://www.marketsandmarkets.com/Market-Reports/unmanned-aerial-vehicles-uav-market-662.html

[13]Autonomous Aircraft Market by Technology (Increasingly Autonomous, and Fully Autonomous), End Use (Commercial, Combat & ISR, Cargo, Passenger Air Vehicle, Personal Air Vehicle, Air Medical Services), Component, and Region - Global Forecast 2030

TECHNOLOGY ROADMAP

The roadmap was developed from the ATI's UK aerospace technology strategy refresh. For the systems priority area, autonomy represented one of the technological challenges that industry is likely to face in the future looking up to twenty years ahead. Within the roadmap, the technology themes of AI and its applications, ML and its applications, big data, modelling and simulation, and quantum sensors were all ranked as the highest priority topics for systems, with input from the ATI's systems technology working group. Further delineation into specific activities within those technologies such as efforts into flight deck development, taxi systems, and infrastructure to support autonomy were also seen as high priority development themes. Underpinning all these were the targets of reducing size, weight, and cost, together with reduction in time from concept to certification, all of which were targets cited by the industry members belonging to the systems advisory group.

DRIVERS

Cost: Reduce cost of certification and system affordability

Operational Needs & Flexibility: Improve maintainability of systems and increased functionality

Energy Efficiency: Minimise fuel consumption through lightweighting and energy management

Environment: Minimise environmental impact through lightweighting and sustainable materials and processes

Safety: Increase automation and autonomy of vehicle control and cyber resilience to maintain aviation safety

Passenger Experience: Improve passenger experience

TARGETS

	2020-2025	2025-2030	2030-2035+
SWAP-C	50% reduction	75% reduction	85% reduction
CONCEPT TO QUALIFICATION	6 years	4 years	2 years

MODELLING AND SIMULATION

- Fully autonomous aircraft command and control
- Advanced modelling and simulation techniques and tools such as digital twin development and enhancement

ENABLER

- Artificial intelligence (AI)
- Machine language (ML)
- Application of ML/AI
- Big data
- Quantum sensors
- Research infrastructure for novel systems concepts
- Regulation and standards to enable intelligent routes to certification

2020-2025 | 2025-2030 | 2030-2035+

CONCLUSION

The vision for the autonomous air vehicle is a vehicle able to carry out a mission from start to finish, self-determining and self-learning with the assistance of autonomous or semi-autonomous UTM and UGAS, without human intervention apart from definition of the flight objectives.

Autonomous systems technology could be truly transformational in air transport, with benefits in both enhanced safety and operating economics. Industry's opinion is that autonomy is on its way - it is just a question of when. For that reason, many academic, industrial and government bodies have identified autonomous systems technology as an important element of their science and technology visions and a critical area for future development.

Autonomy will not happen overnight; there will be a transition period where autonomous air vehicles operate in the same airspace as human controlled ones. In fact, airspace will probably never be 100% autonomous. For passenger air vehicles, there will inevitably be a transition through single pilot operations before full autonomy.

An autonomous air transport system will need to address the following:

- Massively scalable UTM
- Autonomous air vehicles
- Pilots to human supervisors
- Ground infrastructure and operations
- Social acceptance

It will be crucial to consider the air transport system as a whole when developing autonomous approaches – autonomy will be as important for UTM, ground infrastructure and operations as for air vehicles.

The key challenges for introduction of autonomy are:

- Technology – the software and hardware systems that deliver autonomy in air vehicles, UTM, and for ground infrastructure and operations
- Safety and security – the main issues are the route to certification of autonomous systems and ensuring cyber resilience in the face of ever-changing threats
- Social acceptance – the industry needs to engage with the media and the public to inform them about the positive aspects of autonomy

A number of economic benefits are likely to be realised from the move towards autonomous air vehicles, ground infrastructure and air traffic. These include:

A. Better use of airspace (reduced separation) and therefore greater number of autonomous air vehicles potentially in the airspace
B. Increased safety
C. Reduced emissions
D. Creating high value jobs
E. Reduced cost of air travel
F. Spill-over technologies that could be used cross-sector

The ATI, through working groups, workshops and engagement events, will be encouraging the establishment of collaborative partners who are looking seriously at promoting autonomy in all its facets. The ultimate aim of the ATI is to see collaborative projects being submitted for government funding that show ambition and innovation in the sphere of autonomy.

The UK supply chain and wider aerospace sector is invited to comment on this paper, and to consider projects that tackle the key challenges and position the UK at the forefront of autonomous commercial aircraft. Please email responses to the ATI via **info@ati.org.uk** with a subject title of: Autonomy INSIGHT.

The Institute will continue to convene industry, research technology organisations and academia to develop and deliver autonomous systems technology for aerospace to maximise UK economic value.

GLOSSARY

AI	Artificial intelligence
ATM	Air traffic management
CAGR	Compound annual growth rate
CONOPS	Concept of operations
CPC	Connected Places Catapult
DfT	Department for Transport
FFC	Future Flight Challenge
ICAO	International Civil Aviation Organisation
ILS	Instrument landing system
ML	Machine learning
MRO	Maintenance, repair and operations
OEM	Original equipment manufacturer
PACT	Pilot authority control of tasks
PF	Pilot-flying
PNF	Pilot-not-flying
QKD	Quantum key distribution
SOPs	Standard operating procedures
STARs	Standard terminal arrival routes
UAM	Urban air mobility
UAS	Unmanned aerial systems
UAV	Unmanned air vehicle
UGAS	Unmanned ground airport services
UTM	Unmanned aircraft system traffic management

WHO WE ARE

The **Aerospace Technology Institute** (ATI) is an independent not-for-profit company at the heart of aerospace research and development in the UK. Our mission is to raise UK ambitions and lead technology in air transport to maximise the UK's full economic potential. We do this by providing objective technical and strategic insight, maintaining a UK aerospace technology strategy, and together with Industry and Government, direct match-funded research investments – set to total £3.9bn between 2013 and 2026.

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