

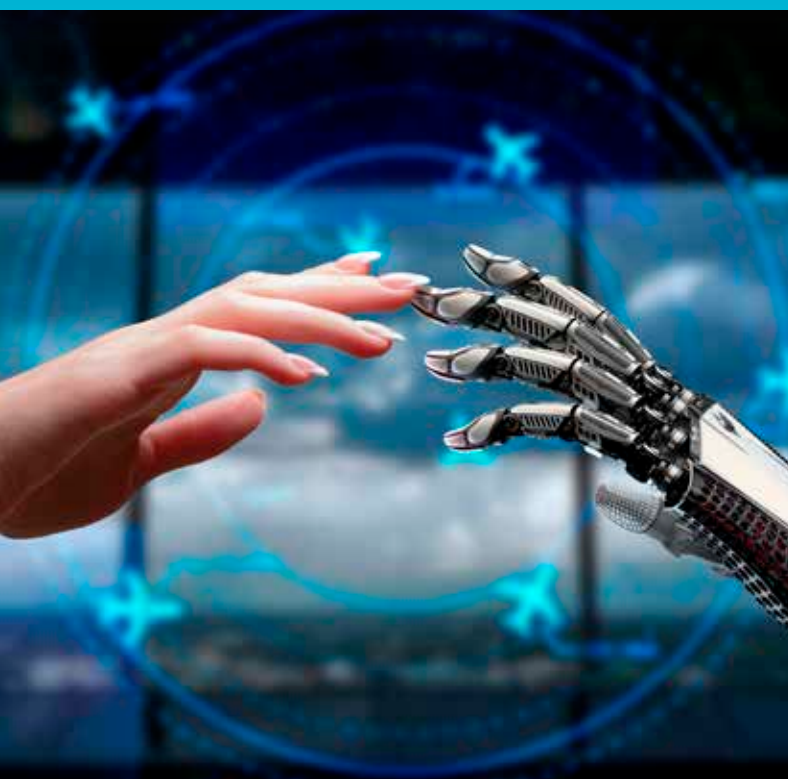


WHITE PAPER

THE HUMAN DIMENSION IN TOMORROW'S AVIATION SYSTEM



Chartered Institute
of Ergonomics
& Human Factors



FOREWORD

The Human Dimension in Tomorrow's Safe Aviation System

The UK Civil Aviation Authority (CAA) is committed to understanding and improving human factors issues for people within the aviation system. Our ambition begins with those we directly regulate and stretches to support the improvement of aviation standards across the globe. This white paper seeks to elevate aviation safety standards by pushing the boundaries of our thinking about how human factors contribute to the complex aviation system of systems.

Encouraging better, earlier and more consistent consideration of human factors in all facets of aviation extends beyond the traditional 'train the individual' approach. To realise further advances in safety as aviation continues to evolve, we need innovative approaches and thinking; the tools in current use may not suffice. The thought leadership articles in this paper encourage the industry to move towards a more robust systems thinking approach. This requires us all to embed early consideration of how to support people to work at their best.

This starts with how we inspire and train people to think about humans, the factors that affect them and how the operational context influences their performance. It needs to become more about understanding how to integrate the human within the system, so that the performance of the human and system is optimised based on their combined strengths.

The paper concludes with a roadmap of possibilities, and we look forward to working alongside the aviation industry as we begin this journey together.

Human Factors

Human factors is a critical component of future aviation success in both military and civil aviation systems, especially where it concerns safety. This white paper contains the visions of 15 'thought leaders', showing how they believe aviation evolution will unfold between now and 2050, and the critical role of human factors in ensuring system performance and safety. The paper concludes by outlining five major destinations for human factors in aviation in the medium and longer term: urban air mobility, intelligent interfaces, future flight crew, the future aviation workforce and future governance.

Introduction

This white paper represents a significant body of work reflecting the expertise, knowledge and thought leadership from an expert group of human factors professionals working across aviation and allied fields. As the CIEHF, we are proud to present the ideas, thinking and challenges about how the aviation industry might evolve over the next 30 years in line with advances in machine learning and how human pilots will adapt.

A wide range of issues are explored in this document from pilotless aircraft, next generation technology for virtual cockpits and the human dimension in future aviation systems. Many of the issues explored cut across themes being examined in other sectors such as those relating to autonomous vehicles, AI and its contribution to digital health, and decision-making in complex systems.

The Chartered Institute of Ergonomics & Human Factors received its Royal Charter in 2014 to recognise the uniqueness and value of the scientific discipline and the pre-eminent role of the Institute in representing both the discipline and the profession in the UK. This includes the protected status of “Chartered Ergonomist and Human Factors Specialist” with the post-nominal C.ErgHF awarded to practising Registered Members and Fellows who are among a group of elite professionals working at a world-class level.

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Aviation today – delivering under pressure

Aviation is a leading edge industry and the safest amongst the four major transport modes. This hard-earned reputation is the result of decades of safety engineering and a strong partnership between the technology and the people including pilots, cabin crew, air traffic controllers, ground handlers, operational support services, maintenance engineers, designers and manufacturers, safety assessors and accident investigators.

Strong pressures exist in civil aviation – intense competition, the ‘greening’ of commercial aviation, globalisation and fragmentation (for example, due to outsourcing) – which challenge aviation companies and potentially narrow their profit margins, reducing their scope for further investment.

Perhaps the biggest challenge in the history of aviation is the ongoing COVID-19 pandemic which is having a dramatic and severe impact on the entire aviation sector. Whilst it’s believed the sector will eventually recover, and this white paper focuses on longer term issues (in fact, this document and all the thought leader pieces were written prior to the outbreak of COVID-19), it nonetheless shows the fragility of the sector to external forces.

In the military sector, aside from intense pressures on defence budgets, the threats to be contended with are ever more complex in a more congested airspace. Militaries around the world are looking for areas where they can drive efficiencies without compromising the defensive capabilities that are essential to their military purpose. Challenges abound with respect to how to maintain the human in command – accountable and responsible for system performance and safety – while managing the ever-increasing amount of information entering the cockpit from on-board and off-board sensors, and the growing use of integrated autonomous systems (including remotely piloted aircraft) to counter increasingly capable and agile threats.

At the same time there are new opportunities – drones, digitisation, new business models, personal aerial vehicles (PAVs), sky taxis, artificial intelligence (AI),

and human augmentation technologies, to name just a few – that offer aviation companies novel ways to add value and improve the services they offer. These technologies offer new ways to train pilots in synthetic environments, measure the pilot’s physical and cognitive state, augment human performance through the use of wearable technologies, and increasingly enable human-machine teaming in all work environments.

A question many are pondering in aviation is how long we will continue to remain human-dependent at the sharp end when research is already working on remotely-piloted aircraft, and AI may soon be knocking on the cockpit door. This white paper concludes that between now and the foreseeable future, 2050, the human will still play a key role in aviation, albeit there will be changes, and there is plenty of room for automation and AI support or augmentation.

This conclusion is partly because those working on ‘level 5 automation’, namely full autonomy, are discovering just how hard it is to achieve in transport systems, unless they are very simple or there are a host of people working remotely behind the scenes to keep things on track. The amount of work required to move towards full automation shows just how good humans are at what they do. The only cheap source of resilience, flexibility, adaptability and common sense is the human, and this is likely to remain so for some time. But advancing technology does mean that we should explore ways to augment human performance and to seek better human-machine partnerships, so paving the way for safe and secure autonomy in the longer term future.

The central question is therefore how to continue to deliver high performance and customer satisfaction while maintaining or even improving safety, and also remaining agile as a business, managing the day-to-day pressures that are endemic in aviation while introducing the new technologies and concepts needed to meet new demands.

A critical solution to help companies and defence organisations stay on top is to get the human element right because people are essential to making aviation work. People deliver strong performance as well as delivering safety. Getting the people part right is what human factors is all about.

Human Factors Core Capabilities

Selecting the right people

- Designing the target audience description and selection criteria
- Ensuring validity of selection tests
- Ensuring staff availability
- Maintaining job attractiveness
- Forecasting staffing requirements

Designing the right technology

- Supporting collaboration
- Integration of interfaces
- Enabling look-ahead prediction
- Managing complexity and uncertainty
- Supporting variable workload
- Keeping the human in the loop
- Sharing situation awareness
- Promoting appropriate trust

Organising people into the right roles, responsibilities and work patterns

- Clarifying inter-relationships between different team players (e.g. pilots, controllers, ground staff etc.)
- Ensuring optimum team performance and intel-sharing
- Managing fatigue and alertness
- Enhancing shared understanding of different roles

Providing the right procedures and training

- Realistic, user-informed procedures (work as done, not as imagined)
- Identifying training needs, including simulation needs and scenario characteristics
- Maintaining rarely used but critical skills
- Designing and maintaining competence standards

Right performance, safety & wellbeing

- Managing the underlying factors – situation awareness, workload, stress – to optimise physical and cognitive performance, minimise error and maximise resilience
- Embedding effective human performance analysis into safety cases and processes
- Supporting physical and mental wellbeing, energy management, and mitigating the effects of stress and incident stress

Managing change

- Analysis of underlying factors and human-human and human-system interactions to support change
- Use of human performance case approaches to support change and mitigate unwanted side-effects
- Managing the social, cultural and demographic factors that impact performance

HUMAN FACTORS TOOLKIT

A long-standing partnership with human factors

Human factors came of age in World War Two via intense study of pilots and the cockpit equipment they had to work with, as well as optimising the tasks of radar operators on the ground. In the decades that followed, human factors concepts such as the human-machine interface, sociotechnical systems, human-centred automation, crew resource management and resilience have all helped enrich the design and operation for both civil and military aviation systems, contributing to the ultrasafe high-performance industry we now take for granted. Although human factors is most known in aviation for delivering crew resource management and for improving aircraft maintenance, it assists in many aspects of aviation system design and operation. In the defence sector human factors is considered a core capability for achieving mission success.

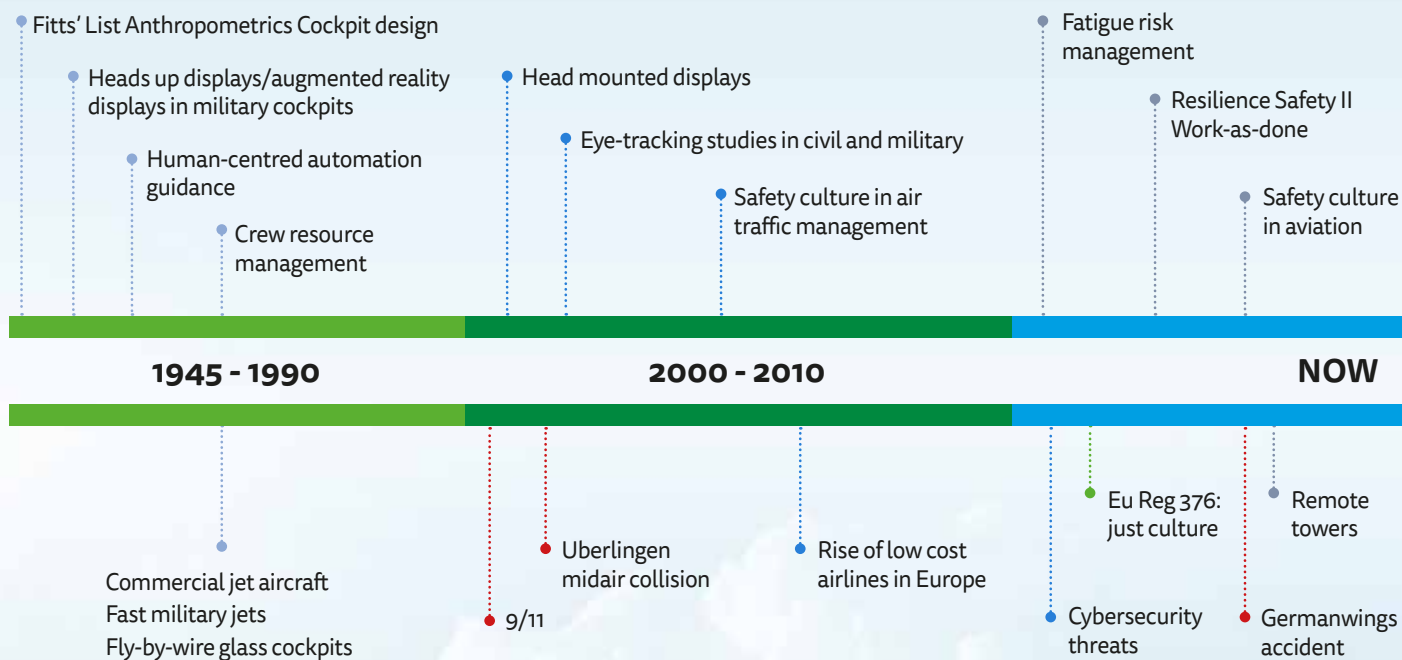
The mission of human factors is to optimise work systems. It is evidence-based, its practitioners drawing knowledge from a number of disciplines

including psychology, medicine, social sciences, design engineering, safety engineering and organisational management. Human factors practitioners in the aviation sector tend to work within a hybrid team, as there is a need to understand both the human and the technology, and how they best interact. The skillsets of such practitioners fall into six core areas:

- 1) Designing the right technology to optimise human-machine interaction.
- 2) Selecting the right people.
- 3) Providing the right procedures and training.
- 4) Organising people into the right roles, responsibilities and work patterns.
- 5) Optimising safety, human performance, and wellbeing in the work environment.
- 6) Managing change.

These are the key areas where human factors has a proven track record and can help today's and tomorrow's aviation companies in achieving safe and efficient performance.

AVIATION TODAY



Aviation safety tomorrow & beyond

There are several 'vision' and 'roadmap' documents outlining the likely future evolution of aviation. Three of note are the Advisory Council for Aviation Research and Innovation in Europe's Strategic Research and Innovation Agenda¹, the Aerospace Technology Institute's technology strategy for future aviation², and the European Union Aviation Safety Agency's vision on the development of AI in aviation³.

The first describes the European vision known as 'Flightpath 2050' and how to get there, via a number of safety, security and human factors goals and capabilities that need fast track development by research to support aviation's evolution. The Aerospace Technology Institute's vision document similarly contains an aviation system development roadmap, outlining how aviation and aerial platforms are likely to evolve in the coming decades. The third and most recent vision document is the European safety regulator's vision of how AI is likely to be integrated into aviation systems, from initially being a collaborative element, to fully autonomous aviation systems based on AI in the 2035+ timeframe. Notably, the European Union Aviation Safety Agency's vision calls for human-centric AI.

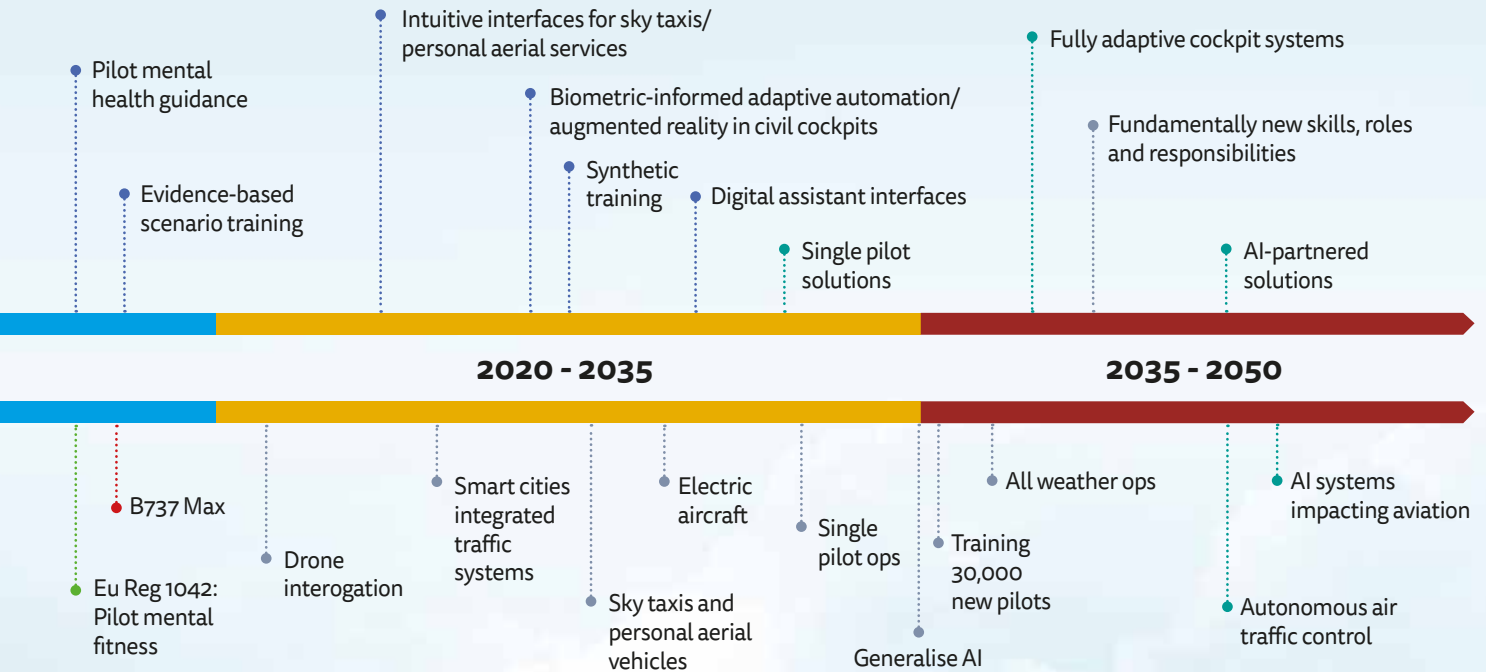
Human factors in aviation – past, present and future

The timelines predicted by such documents vary of course, as no one really knows when new vehicles, etc. will become operational, especially in the civil aviation transport sector. But the roadmap above offers a timeline incorporating past and recent events, as well as future events that will drive the need for human factors research and innovation.

Human factors, like aviation, is also future-focused, and because it has a strong research base, it can help companies and organisations who wish to invest in future performance. Improving reactions in the cockpit during adverse weather conditions via scenario-based training, developing augmented reality displays and adaptive automation, moving towards single pilot operations, and interfacing with future AI systems. These all fall within the scope of human factors, as highlighted in the roadmap above, which chronicles some of the key events, challenges and achievements from the past until now, and the key destinations for change for the future.

1 www.acare4europe.org/sria 2 www.ati.org.uk/media/siybimmm/ati-tech-strategy.pdf 3 www.easa.europa.eu/sites/default/files/dfu/EASA-AI-Roadmap-v1.0.pdf

Human Factors in Aviation Vision and Roadmap



Aviation's accelerating evolution

Until recently, aviation has largely charted its own course aided by technological advances, most of them directed by the industry itself. The public were generally happy to travel, besides a few sticking points such as airport expansion, local noise, and of course tragic accidents, which have become steadily rarer despite soaring increases in air traffic.

Now there are massive technological changes ongoing outside aviation (for example AI), and societal values affecting it (climate concern related to carbon emissions), and societal-technological interactions (cyberterrorism and cybercrime), plus the recent ongoing COVID-19 pandemic, that threaten aviation companies' very existence.

These seismic shifts in the world of aviation trigger two major questions:

- 1) What are the main challenges now, in the midterm future (2025-2035) and in the long term future (2035-2050)?
- 2) How can human factors help aviation not only overcome them but thrive and prosper in the future?

The key issues are outlined over three timeframes. Particularly for the medium and longer timeframes, not all of these issues or approaches may come to pass, and indeed some may seem to be conflicting. But at present they are the likely future avenues and so should be explored by research and innovation so that the best options will be available to the industry.

The key 'now' issues (2020 – 2025)

There are a number of 'now' issues, some of which human factors is already addressing:

- Return to operations following pandemic protective measures.
- Fatigue risk management.
- Pilot mental health.
- Corporate social responsibility.
- Dealing with faulty automation – when to turn it off, when to turn it back on.
- Maintenance error management.
- Assuring safety and just culture with new business models (for example low cost).
- Evidence-based training for adverse conditions (for example flight upsets).
- Maintaining safety and performance with single and multiple remote towers.
- Cybersecurity threat management.
- Pandemic containment.
- Interoperability of military assets.
- Remotely piloted aircraft and drone integration into commercial airspace and urban environments.
- Systems thinking across the industry to allow more effective and efficient integration of human factors into design, operations and safety management.

These issues largely concern current pressure points, for example, fatigue and mental health concerns with pilots, faulty sensors interacting with automation leading to pilot confusion at critical points in the flight, ensuring safety and just culture are maintained during intense competition. Added to this is a more general issue of technological advances outpacing regulation. In such a climate, it's often the human element that must make new systems work while keeping them safe and interoperable.

The key midterm issues (2025 – 2035)

In this timeframe there are a number of major challenges where the people element will be a key determinant of system performance and safety:

- Supporting the management of change in aviation organisations associated with external pressures including digitisation, disruptive technologies, new vehicles (electric and hybrid), climate change, integrated (multimodal) transport systems and smart cities, and societal attitudes concerning transportation.
- Enhanced automation in the cockpit including augmented displays and adaptive automation.
- Changing human roles requiring different skills and knowledge as well as increased interaction with complex automation.
- Development of AI-based digital assistants wherein automation advises pilots and others in real time, based on explainable AI technology.
- Optimised interfaces and training systems for sky taxis and PAVs.
- An increasing shortage of pilots in commercial aviation (assuming operations have returned to and exceeded pre-pandemic levels).
- Single pilot operations (initially cargo, then passenger aircraft).
- In the military sphere, the capability to deal with a more congested and contested operating environment.
- Increased use of synthetic training devices in place of live training to provide the capability to train in complex scenario environments with distributed participants.
- Control of multiple military assets from a single airborne or ground based asset.
- New regulatory frameworks to cope with certification of distributed and AI-based systems.

These issues all require significant research and development. Many, if not all of the above issues will have system-wide effects, some of which will be planned, whereas others will simply emerge. Drones are a case in point: as little as six years ago everyone was thinking of RPAS (remotely-piloted aircraft systems, also known as UAS – unmanned aerial systems) as basically small unpowered aircraft controlled by a remote pilot facing a number of screens. Few were envisaging swarms of much smaller semi-autonomous drones for domestic services such as deliveries.

This is an example where aviation regulators are having to catch up fast, learning to deal with a whole new set of stakeholders who are themselves new to aviation, and trying to balance societal benefits against safety considerations while factoring in ethical considerations such as privacy.

Whereas today there are several hundred airline operators, in a few years there will be tens of thousands of drone organisations and that does not include the countless number of personal users. This is where, on the civil side, human factors can help the industry stay ahead of such societal shifts, acting as a societal radar, mapping the cultural and societal changes and their effects onto the aviation business.

The key long term issues (2035 – 2050)

Given what the recent past has shown us, with the advent of disruptive technologies and the meteoric rise of social media, predictions of long term goals can only be seen as a best guess. Nevertheless, certain predictions have been made:

- Autonomous (AI-supported) air traffic control and aircraft.
- Fully adaptive cockpit automation systems that monitor pilots and controllers via biometric sensors, and support or take over when needed.
- Large scale induction and training of pilots (despite the growth of single pilot and pilotless aircraft).
- Full integration of air traffic – piloted and pilotless civil traffic, PAVs, sky taxis, drones – and seamless connectivity with other transport systems (rail, road and sea).
- Adaptive control of unmanned assets from single seat military aircraft.
- Brain-computer (neural) interfaces.

Such long-term developments in aviation will almost certainly require a step change in the way aviation works and will result in far more complex air traffic operations by 2050.

Achieving these goals

All of these goals – now, midterm and long term – will require significant research and development to ensure they add real business and societal value and remain as safe, or even safer when compared to today's operations. All of them will benefit from effective partnering with human factors. The purpose of this white paper is to elaborate on these future visions, to see what the future might look like in more detail. But it's also to determine if there are key waypoints or destinations, to help provide a common focus for key research and development threads so we can navigate safely and efficiently to 2050. Such destinations, whilst dealing with key human factors challenges, need to be industry-centric and relevant to regulatory authorities.



FUTURE AVIATION

How thought leaders see future aviation

The centrepiece of this white paper is a set of invited, concise editorials from leaders in a range of aviation human factors related areas:

WHAT WILL THE FUTURE LOOK LIKE?

1. The key human factors challenges – perspectives from a global aircraft manufacturer.
2. A view from the cockpit.
3. The changing aviation skyscape.
4. Future aviation warfare.
5. Human 2.0 – who will we be in 2050?

KEY TECHNICAL AND SOCIOTECHNICAL CHALLENGES

6. The AI enigma.
7. AI or intelligent assistance?
8. Single pilot operations.
9. The changing social landscape of commercial aviation.
10. Will we control the automation or will it control us?
11. The human role in autonomous warfare.
12. Future training.

REGULATORY CHALLENGES

13. Innovation and future regulation.
14. Reducing vulnerability to human error: a total systems approach.
15. The future of safety cases.

The aim of these editorials is to show a more elaborated vision of the future, so that appropriate research avenues can be identified. It's impossible to be comprehensive but the pieces have been selected to give a broad spectrum vision of the likely unfolding future of aviation. Editing has been kept to a minimum so that each piece stays true to its author and their working aviation context, whether as an airframe developer, a commercial airline captain, a military training system adviser or a regulator.

The editorials have been written independently, so can be read in any order (though they have been placed in an order that has a certain logical flow), or the reader can peruse the visions of most interest to them and then go straight to the final section, considering the five destinations outlined at the end of the document.

Note: As mentioned earlier, this entire document was ready for publication just prior to the COVID-19 outbreak, and it was not practical to ask each thought leader to re-adapt their pieces. The editors have sought to ensure there are no insensitivities in the document, relevant to the profound impact the pandemic is having on the industry, but the pandemic is an unprecedented (at least in modern times) and dynamically evolving situation. You are therefore asked to understand that all the thought leader pieces, and indeed the entire document, have been written in good faith in order to help support the safe evolution of the industry.

WHAT WILL THE FUTURE LOOK LIKE?

1. The key human factors challenges: perspectives from a global aircraft manufacturer

Written by [Florence Reuzeau, Airbus](#)

Looking towards the 2030-2035 horizon, large commercial transportation will be more sustainable and ultrasafe when securing business revenue. Airbus is looking at making aircraft even more resilient while maintaining a pilot-centric approach, as the following examples show. Different alternatives are explored and there is no specific calendar but the first applications could happen in the next ten years.

The reorganised multicrew operation, often called reduced crew operations, is an add-on of the current multicrew operation that could be applied on modern aircraft. At the crew's discretion, during a certain part of the cruise phase when workload is low, one pilot can take advantage of a resting period in an appropriate facility while the other pilot is flying the aircraft. For the remainder of the mission, the aircraft is managed with two pilots at the controls. To enable this, the aircraft should be even more resilient than it is today, to assist the pilot in their tasks. This should reduce the fatigue of the pilots which is identified as a recurring safety issue and common within the aviation community.

Single pilot operation is a very different concept, with one pilot seated in the cockpit for the entire flight, including take-off and landing. It can be applied to short-range operations and will require a new cockpit concept and major changes to alleviate the workload and mitigate the risk of pilot incapacitation – for example a permanent autoflight and the capability to land at airports that are not necessarily equipped with a instrument landing system or ground-based automation system. Airbus is experimenting with image processing to add a level of redundancy in the navigation system. Image processing may also be a key technology for detecting obstacles. This surveillance function must be coupled to predictions of trajectories and conflict resolution functions.

The introduction of smart systems such as cognitive

assistants or artificial intelligence systems opens up a new field of human-system interaction requirements which will be necessary to develop an effective cognitive interaction, or so called 'human-machine teaming'. When a human is cooperating with an intelligent system to perform decision making, the quality of human-system interaction contributes to the overall performance. A cognitive assistant should be able to perform abstract reasoning using data that is not precisely perceivable by humans. Therefore, the cognitive interaction should be designed in a way that the human can accept that the cognitive assistant will influence their behaviour in a reciprocal manner. This means the cognitive assistant should act as a kind of social agent and endorse social intelligence requirements as a part of its cognitive interaction qualities. The famous human factors criteria such as explainability and mutual understanding – so debated in the early stages of artificial intelligence – are in the spotlight once again.

The humans in these future concepts will be at the centre of the operations. They will make the strategic decisions – the choice of a diversion airport for example – supported by the machine and the connected environment. Enhancing human performance can utilise the following principles:

- Humans perform well when they can anticipate. The machine must provide contextualised information and data to assist with any planning task.
- Humans will perform even better if they have enough time to act in an environment without stress. The machine could support any failure management by providing a higher level of resilience.
- Human performance can be affected by human errors (part of our normal behaviour). Human self-awareness functions could be offered to the pilots to have direct feedback of their activities.



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The objective is to utilise the best of both worlds: a human making strategic decisions while systems are taking care of everything else.

The objective is to utilise the best of both worlds: a human making strategic decisions while systems are taking care of everything else. This could include continuing a safe flight and landing in case of pilot incapacitation.

However, the increased use of smart systems must not divert attention away from the real questions: where is the place for the human operators? From a human factors perspective, the question of human role and responsibilities is paramount. How do we define roles and responsibilities to be sure that the jobs offered to the human operators will make sense for them? One of the challenges is to define jobs that do not mechanise the human but instead allow them to engage their

intelligence and sensory skills, coupled with a potential for growing capacity and increased motivation.

Aerospace evolves slowly but, when looking back, safety has dramatically improved over time and this remains the priority today. Undoubtedly, the role of the human operator will be essential in these future concepts. Our human factors and social sciences community is encouraged to assume a key role in defining the appropriate human-machine teaming requirements. The next evolution should come from even more collaborative projects within the air transport system. Human factors will remain a key partner.

WHAT WILL THE FUTURE LOOK LIKE?

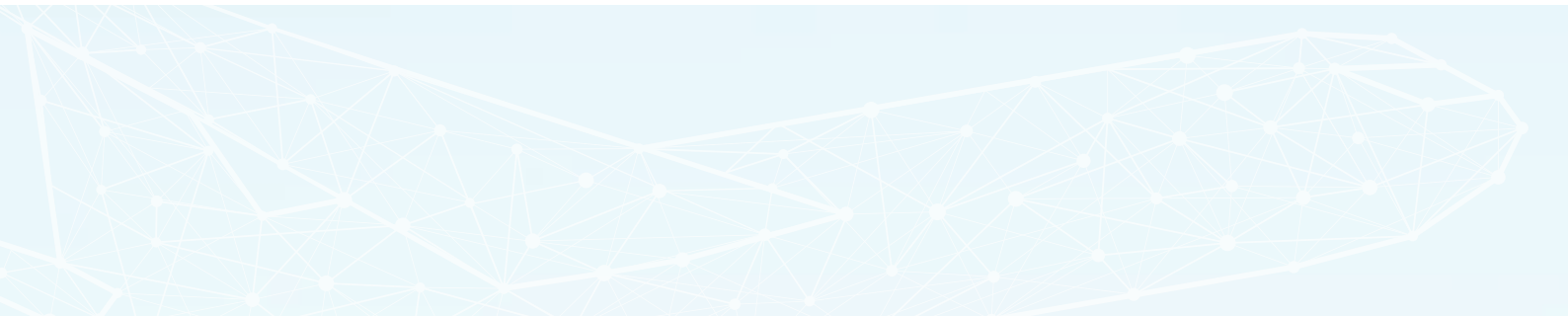
2. A view from the cockpit

Written by **Carsten Schmidt-Moll, Lufthansa Captain**

Today's modern aircraft are all very similar, whether they are from Airbus, Boeing, Bombardier, Embraer or any other manufacturers. And the life of a pilot is easy – when everything works fine. But whenever a technical problem occurs, the situation can change rapidly, suddenly requiring excellent collaboration and communication, procedure handling, situation awareness, decision making and manual flying skills. Under such circumstances, the quality of automation and the human-machine interface determine the amount of cognitive resources left for the pilots. Important information must be immediately at hand, not scattered amongst different documents and applications.

After the pilot and cabin crew, the safety of the flight comes down to two main computer systems which are available to the pilots: the electronic centralised aircraft monitoring system (ECAM, as used by Airbus) or the engine indication and crew alerting system (EICAS, as used by Boeing and Embraer) of the aircraft and the electronic flight bag (EFB) from the airline. Their content is presented in one or two vertical screens in the middle of the cockpit so that both pilots can see and work with it. As these systems are built into the aircraft, it's part of the certification process of the manufacturer. As the certification process is very complex and time consuming, only minor changes may be conducted throughout the years of production and





usage of the aircraft. During simulator training, pilots learn how to handle technical problems or 'abnormals' with the help of the ECAM or EICAS.

The EFB is an add-on from the company, usually a portable tablet which includes maps and documentation, as well as multiple additional functions and tools. It is mounted on the side of each pilot's cockpit window. During normal operations it serves as a reference book or library and usually just helps to improve the efficiency of the flight. During abnormal operation however, the EFB contains all safety relevant information such as aircraft systems, operational limitations, information about airports, etc. It has the potential to be the biggest pilot help and support in an abnormal or emergency situation.

Access to safety relevant information during an abnormal situation is of paramount importance. While all relevant information is available on board, today it can take time to access it, and you have to know where to find it. This can result in too much 'head down' time during critical situations when the crew must still fly the aircraft.

Given the huge security concern among computer scientists and airline specialists that a virus or trojan may get control of the aircraft, the EFB has no interface with the aircraft and its flight management system. Yet if one could overcome today's security problems and connect the EFB with the aircraft and provide internet access, then using electronic devices in the cockpit would enable a completely new ball game. The EFB would constantly know the system state of the aircraft, every technical failure and the amount of fuel on board. Having access to the internet, the EFB would also have the latest weather information and runway conditions available. As an example, during snowfall with contaminated runways, the EFB could suggest airports which are suitable, for example the ones with sufficient landing distance. It would not be responsible

for making that decision but its support to the pilots would already be enormous.

The usage of AI will be the next inevitable step for the EFB and the pilots. AI is not supposed to mimic the pilot's thoughts and processes but it may solve problems through the use of best possible algorithms, and even make decisions of its own thus minimising the role of the pilot. In the example above, the EFB could already inform the airport of an intended diversion. The challenge of AI is to keep the pilot in the loop at all times. For example not informing the airport about the diversion without the pilot knowing about it.

Additionally, the pilot should always be able to intellectually follow the recommendations of the computer and even with the most sophisticated AI available, the pilots must always be able to reproduce its recommendations. This 'rapidly explainable AI', in sudden crisis situations in the cockpit is a major human factors challenge

The development of the aircraft's ECAM and EICAS is hindered by the legal need for certification. The EFB does not (yet) have such constraints. There could be a perfect application for technical abnormalities or even emergencies. Due to its internet access, it might need a fair amount of self-discipline to use it properly and avoid distractions. It will definitely improve the safety of the flight, just like our smartphones have modified and improved our daily routine.

The integration of multiple data sources including internet access and technical support from airline operations centres, will also revolutionise the abnormal and emergency handling in flight. The future is about the partnering between intelligent systems and human systems that both deliver a robust safety and service under all conditions, leveraging the best of human and digital capabilities.

WHAT WILL THE FUTURE LOOK LIKE?

3. The changing aviation skyscape

Written by **Barry Kirwan, EUROCONTROL**

Futuristic visions of cities often show an assortment of air vehicles zipping around skyscrapers, narrowly dodging each other. Until recently, such visions have belonged to the realm of science fiction. Now however, the future architecture of urban airspace is being redrawn. Drones are on our doorstep, occasionally causing havoc with airports, although so far there have been no fatal drone accidents. Sky taxis will soon be operating, electric aircraft will be introduced to reduce aviation's impact on climate change and AI will inevitably seek its place in the cockpit. Whilst it's easy to imagine a seamless integration of new vehicles into our skyscape, especially when technology seems to be advancing at an almost supersonic rate, it's less straightforward to determine how to realise this future transport vision safely.

By 2030, so-called megacities are envisaged. Given that in most big cities today road traffic congestion is a major issue affecting health, quality of life and productivity, shifting some of our mobility needs to the sky (and to rail) is an obvious solution to consider. Yet already there are signs that the societal appetite for aviation transport has limits. One example is the 'flying shame' phenomenon, which may be expected to further evolve post-COVID-19, another is the growing concern over the high-pitched whine of drones – not nearly as noisy as aircraft but with a higher and more widespread potential annoyance factor. Add to this privacy concerns related to drones, and it's clear that those designing the future architecture of urban airspace will not have carte blanche.

Then there is the question of managing all this urban sky traffic safely. Simply equipping every drone with see-and-avoid technology will probably not be enough once drone traffic density reaches a certain (as yet unknown) tipping point. Yet the robust-yet-rigid model of pre-filed flight plans used today for conventional air traffic will not be agile enough for a heavy and heterogeneous urban traffic load.

One potential long-term (post-2030) solution is that of AI, which could in theory control a vast amount of urban traffic safely in real time. The 'in theory' qualifier is important – this is not yet a done deal, it would have to be proven to the regulators that such a tech solution is better than the human one that has fared so well for decades, or else society will have to accept increased accident rates. The challenge therefore is how to integrate all these new systems into our airspace and living space while remaining safe from harm, as well as secure from cyber or other attacks whose threat platform enlarges as we digitalise and automate.

Options such as single pilot cockpits and AI assistance in the cockpit provide significant challenges for aircraft designers and pilot communities, not to mention safety regulation authorities and human factors specialists. Such design concepts are literally taking one safety barrier out of the equation and/or replacing it with another that can never be fully tested due to its inherent complexity. While passengers already accept some urban rail transportation systems with no driver, and driverless cars are approaching fast, how comfortable will passengers honestly be flying in a metal cylinder at 500 miles per hour with nobody at the front driving it?

Most likely, this transition will not be a step change but an evolution: single pilot cockpit, remote control via a pilot managing more than one aircraft with a backup pilot still on board, then remote control only, then, perhaps by 2050, full autonomy. Such evolution will benefit from human factors predicting and managing the human-system performance and associated risks as well as navigating societal concerns as they arise.

Human factors is key to the development of safe and efficient user-centred interfaces whether in the cockpit, the air traffic management system, the sky taxi or the personal vehicle. Added to this are the training and procedures required to ensure the system remains safe and efficient.



Safety culture, whether in militaries, airlines, airports, air navigation service providers or airframe manufacturers and equipment suppliers, needs to stay at the forefront.

At a deeper level, human factors will be key to getting the balance right between human and machine intelligences, whether such AI systems are assisting the pilot when encountering difficulties such as adverse weather, managing the urban air traffic system or flying the vehicle all by themselves.

At a deeper level still, human factors is needed to help ensure that the generally strong safety culture evident in aviation isn't eroded by narrowing profit margins, or by new business entrants unused to the very high standards of safety that have been so hard-earned in the industry. Safety culture, whether in militaries, airlines, airports, air navigation service providers or

airframe manufacturers and equipment suppliers, needs to stay at the forefront. New entrants must be exhorted to follow existing best practices (for example on just culture and reporting), albeit in a possibly more agile way. Senior management must continue to maintain a strong focus on safety as well as the bottom line. Otherwise, aviation will lose its much prized first place in transport safety.

The coming decades will transform our skyscape, and on this journey from the realm of science fiction into reality, human factors needs to be there to help ensure we all have a safe and comfortable trip.

WHAT WILL THE FUTURE LOOK LIKE?

4. Future warfare

Written by **Nick Colosimo, BAE Systems**

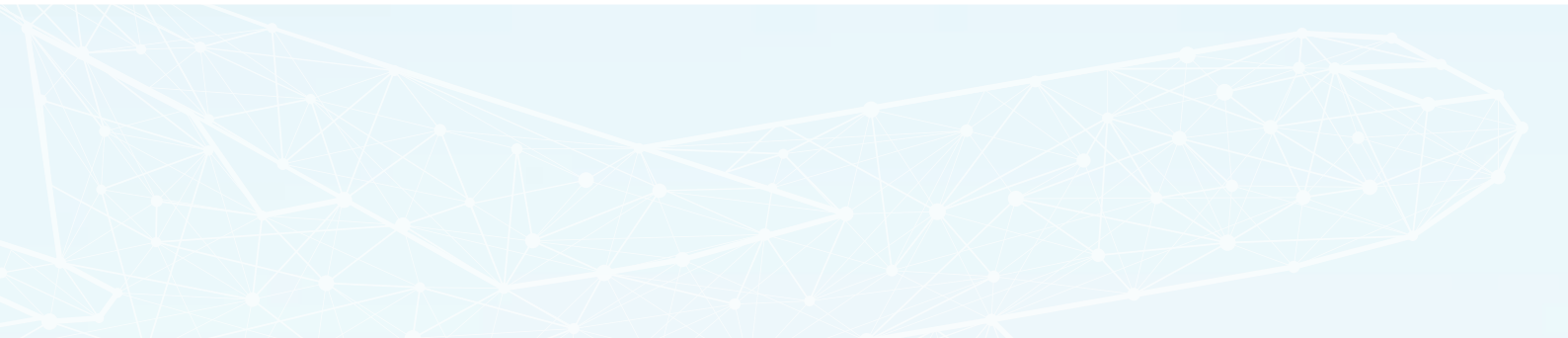
The future operational environment presents many challenges that affect future military aviation and the role of humans. This is a reflection of advancing adversary capabilities and increasingly congested, contested, complex and chaotic operational environments.

Adversary capabilities relate to effects and sensing. Effects include conventional effects such as bombs, bullets, and missiles and near instantaneous attack methods from electronic warfare to cyber-attack. Longer range surface-to-air missiles and higher speed weapon systems such as hypersonic missiles and hypersonic military aircraft are emerging and

are considered a serious threat. These will be joined by even faster engagement weapons such as laser and radio frequency directed energy weapons. When combined with sensor technologies on the ground, in the air and in space, that are able to detect, track and engage military aircraft at significantly increased ranges, the ability to enter an adversary controlled environment is becoming incredibly difficult for military vehicles without suffering high attrition.

The operational environment is also becoming increasingly congested in both physical and electromagnetic terms. The world population is expected to reach between eight and ten billion by





2045 with the majority living in urban environments and megacities with increased ground and airborne traffic including autonomous vehicles. By 2040 there will be significantly in excess of 96 billion internet connected devices worldwide, and this trend is mirrored in military circles. Available radio frequency bandwidth is often difficult to find and utilise even when the adversary isn't attempting to control the spectrum.

As a consequence of the above, there is a strong driver to leverage from developments in artificial intelligence and machine learning to help us make sense of the world and the battlespace. Increasingly automated and autonomous systems will be necessary to better the adversary's OODA loop (observe, orient, decide and act) and to overcome the issues associated with contested physical and electromagnetic environments. Combine this with faster action through the higher speed effects mentioned earlier, and we are approaching an era of machine-speed warfare where a large part of the OODA loop is essentially automated and therefore occurring faster than it is today.

The question arises as to what this means for military aviation and the role of the human. In all cases the humans who are accountable and responsible for system performance must be able to trust the automation and this means that it has to be reliable, predictable and explainable. Legal and ethical matters are of paramount importance. If they are to avoid becoming a bottleneck in future machine-speed warfare, then a means of augmenting the human ability to rapidly gain situation awareness and make faster and better decisions in complex and chaotic environments must be found.

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The future operational environment presents many challenges that affect future military aviation and the role of humans.

Technologies are emerging in which greater human augmentation can be attained, including: augmented, virtual and mixed reality interfaces; psychological and physiological monitoring devices; affective computing; and brain control interfaces. However, you must consider the situation in which no human could ever respond fast enough to a situation irrespective of the level of augmentation they receive. In this case we need to decide what we can – and are prepared to – delegate to a machine, noting that there will be an impact of not doing so, as well as the impact if we do. This requires a framework, strongly informed by human factors, relating the required speed of response and necessity (including the consequences of not acting) with the appropriate overlays of legal, ethical and other boundaries such as societal acceptance. Until such a framework is adopted it will be essential to engineer solutions that are flexible and scalable such that they can be adapted in a timely manner to meet the increased military challenge.

WHAT WILL THE FUTURE LOOK LIKE?

5. Human 2.0: who will we be in 2050?

Written by **Claire Dickinson, former CIEHF President**

What do we know? What can we reliably predict? By 2050 there will be around nine billion people on the planet, consuming ever more resources and leading ever more technologically complex lives. The use of renewable energy and recycling of resources will be custom and practice. 90% of cars will be electric. Low carbon companies will be the norm. Will we be commuting to work? I think so, but more likely in the connected world we will travel to local work hubs and link to our co-workers, wherever they are located, because people are social animals and recognise they benefit from the challenge and nods gained with the interaction of others.

By 2050, people will, on average, have 25 connected devices at their fingertips. The immediacy and analysis of digitalising records, images and databanks, will mean faster, more reliable, automated diagnosis and problem resolution, whether at work or in our daily lives. Computers will be around 30 thousand times faster and smarter than they are today. Non-human, super-intelligent AIs will exist.

The use of drone technology will be very visible and taken for granted. Their use in photography or recording live action events is already established but there is tremendous potential for greater application in business, including the aviation sector. They will provide delivery services, they will ease monitoring or surveillance activities, for example of crop growth or the state of the airport infrastructure or rail network and assist in dangerous mountain or sea rescue missions.

Robots will replace many of the physical tasks we perform, not only in manufacturing, but also in the service sector, from cooking our food to cutting our hair. Robotic aviation ground handling, refuelling operations and baggage handling are very likely.

Such changes will impact on the jobs landscape. To avoid joblessness people will need to be smarter and

better educated. It's a transition that will be felt at the individual level both economically as well as socially. At an organisational level, more goods and services will be cheaper, as the costs of wages will be removed from the pricing strategy.

By 2050 we will have human-like assistants. They will resemble people so much that by interacting with them we will satisfy many of our social needs. Interacting with robots will be much easier. They will not have their own will (as their sole purpose will be in serving us), they will not have feelings, they will not get angry, annoyed or tired. Therefore they will be perfect companions as we will no longer have to take into account their needs or wishes and compromise with them. Human-to-human interaction will be reduced, as dealing with other people can be difficult.

Visualisation software tools will be used by all, not just those virtually walking through new infrastructure designs or kitchen showrooms. Simulation, virtual reality, augmented reality technology – already in place by the military for training – are likely to be found in safety-critical activities, including the training of airline pilots. The greater use of surveillance technologies enables the possibility of fewer control towers being located on site, instead being remotely positioned, providing a wider range of aviation control services.

As for society, culturally people will be different, too. People will expect more and demand better products and services, requiring enhanced passenger experience on all forms of transport, including aviation. Two-thirds of the world population will be living in cities, and urban air mobility (drones, sky taxis and personal vehicles) will become commonplace, as will more interconnected transport options. The largest age cohort for the European population will be 60-64 years, but for the United States 20-35 years, India 35-39 years. The implications of this to economic activity and growth is staggering! Staying competitive will require a



focus on the strategic aspects of the job; robots can do a lot, but they cannot brainstorm, motivate or inspire people.

What will be the impact on travel? With better connectivity, it might be projected that the need for air travel will have decreased but there is another school of thought that air travel provides a way of allowing movement of people in a more controlled, secure way and is therefore preferred, given the trending issues of illegal or mass immigration and terrorism. Following the COVID-19 pandemic, this is an area that's likely to receive strong attention.

The aviation sector is already paving the way for more fragmentation and personalised service delivery, such as sky taxis. Digital connectivity and embracing

ever more technology is bolstering our growth and productivity. Efforts, such as on crowd management systems, using machine learning to avoid blockages at airports, and on accessibility, are enhancing the passenger experience and supporting the delivery of a safe and secure way of travelling. The political, technical, economic, social and environmental factors must all align to see increased growth, productivity and wellbeing for Human 2.0, including a stronger focus on the environment, achieving greener (carbon neutral) air travel. As technological advances reshape our lives, we will need human factors as a counterpoint, as a discipline that always puts humans first, to ensure this transformational journey remains a positive experience.

KEY TECHNICAL AND SOCIOTECHNICAL CHALLENGES

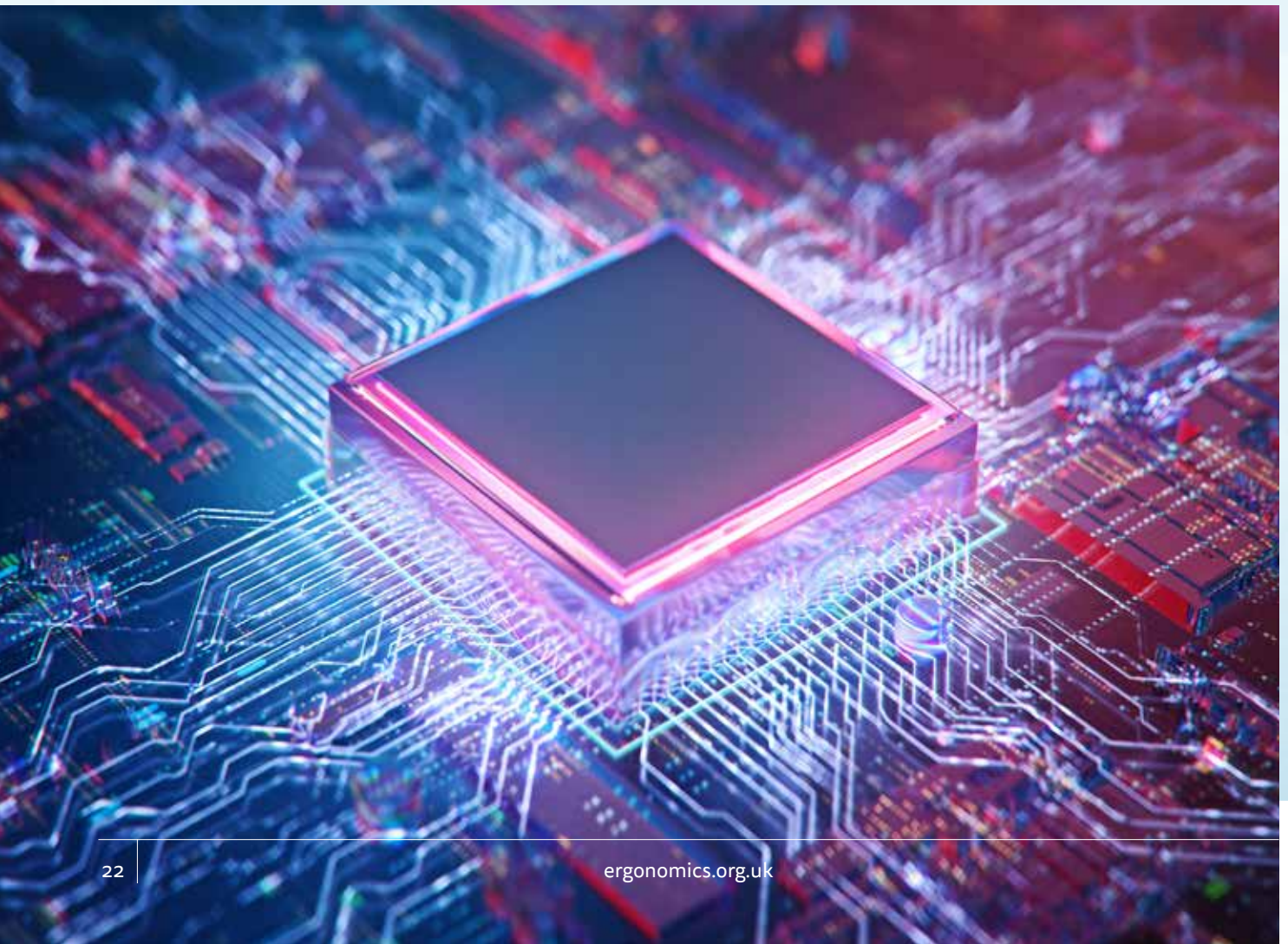
6. The AI enigma


Written by **Chris Baber, University of Birmingham**

Alan Turing famously asked “can machines think?” and proposed the Turing test in which a computer tries to persuade a human judge that it is human. Early versions of AI passed the Turing test in the 1960s by taking words and phrases from the human and simply recombining them and presenting them back to the person. Here, the AI was adapting to the incoming information but not obviously doing something that was intelligent, though defining what ‘intelligent’ means has been a continual challenge to the AI community.

AI is popular again due to the promises of machine learning, with successful applications in mining very

large data sets and discovering useful patterns applied to threat and target classification, management of air traffic, scheduling of preventative maintenance and optimisation of aerofoil design. In these approaches, rules are hyperparameters that can constrain the resulting classification. In machine learning, a human programmer still defines ‘goodness of fit’ in the classification and selects appropriate data sets that can produce generalisable results. Problems with either the definition of ‘fit’ or the selection of data sets can lead to algorithmic bias, in which the results might be appropriate to the available data, but could be unacceptable socially, ethically or operationally. Verification and validation of such algorithms remains





challenging but will be critical for safety-related applications.

The 1970s and 1990s saw two 'AI winters' in which AI research stuttered due to a lack of confidence in the performance of expert systems (which promised computer intelligence that could equal that of a human expert, for example, a physician). While these early expert systems could perform impressively on highly constrained problems, they struggled to cope with ambiguous or nuanced problems. For critics of AI, this problem represented a deeper issue of AI lacking common sense (the ability to generalise beyond the constraints of the information provided). There was also a problem of combinatorial explosion. After the first two moves of a Chess game, there are 400 possible next moves. In Go, there are close to 130,000, making it impossible to search this space in a brute force manner and so a different approach was required.

In contrast to machine learning, contemporary AI systems do not use predefined rules or patterns. Instead they seek to learn a policy for acting in order to maximise a reward and minimise a cost. AI can perform millions of simulations in order to optimise its policy. In this way the AI discovers rules, some of which human players might find surprising, novel or difficult to comprehend. The moves such an AI comes up with are out of our hands. This makes the question of bias more difficult to fathom and has led to calls for explainable AI. Current approaches to explainable AI focus on post-hoc interpretation of the actions of the AI in the face of the information available to it, but it's unlikely that this will reveal the underlying processes the AI was following. Furthermore, the breadth of algorithms employed by AI means that the patterns being discovered can be fooled; there is a whole area of research in which image recognition by AI can be fooled by changes in one or two pixels, for example,

misrecognising a stealth bomber for a dog. In such instances, AI still lacks the common sense required to inform and constrain its interpretation. More practically, hostile actors may seek to spoof, distract or otherwise interfere with AI image recognition.

The holy grail is a general AI capable of responding to any situation it encounters by reasoning about the information available, combined with the knowledge it already has, and selecting the appropriate action. For some, only when general AI is developed can we use the word 'intelligent'. For others, general AI is seen in terms of the threat of machine intelligence surpassing that of humans, for example, for Stephen Hawking AI could represent an existential threat to humanity.

Human factors, particularly in the field of aviation where AI is intended to first support and perhaps one day replace the pilot, is well placed to help frame the growing societal debate about general AI and explore its boundaries in terms of systems thinking. Human factors should also be able to determine how humans and AI can cooperate to create a joint understanding of a situation, the decision options and the consequences of acting on those options, leading to human-AI 'teaming', with performance that can surpass either human or AI alone. Additionally, legislation and regulation will inevitably shift its focus from considering solely the reliability of AI (such as a utilitarian perspective on ethics that seeks to minimise cost and maximise general benefit) to encompass broader concerns of bias and the social impact of AI. Human factors could develop new approaches to make sense of the behaviour of systems that allow exploration of ethical implications and societal impact. Such implications should be fully understood before Turing's test is finally and convincingly passed by a general AI.

KEY TECHNICAL AND SOCIOTECHNICAL CHALLENGES

7. Don't give us AI, give us intelligent assistance (IA)

Written by [Sylvain Hourlier, Thales Avionics](#)

We're all aware of the rapid changes to our way of living. Everyone owns those wonderful pieces of equipment (smartphone, smart TV, connected appliances, even our basic PCs – the list goes on and on) that we use without really mastering them. When they perform, we perform (most of the time) but whenever anything goes wrong we become helpless, facing a void of incomprehension where we unsurprisingly fail. These technologies can suddenly turn silly, obscure and counterintuitive because of their inherent (usually hidden) complexity. If the situation is critical, consequences can be extremely severe. Pilots can also be in situations where they have to face the critical emergence of hardly manageable complexity. In the near future, aviation will face four challenges that aren't going to help us:

- 1) In the longer term, air traffic will likely continue growing due to emerging countries and population growth, thus increasing aeronautical environment complexity.
- 2) Similarly, in the longer term, a shortage of pilots will impact recruiting standards, so reducing their potential performance.
- 3) Pilots' nurtured lack of awareness on potential complexity due to benevolent, yet fallible masking automation.
- 4) The icing on the cake being that global warming may induce far more exceptional, therefore complex, weather situations never experienced by pilots.

Even at a constant technological complexity level (which won't be the case) in the cockpit, the combination of these four factors will lead to an emergence of unknown, unforeseeable and formidable. So far, the answer has been to increase training. But even if we could anticipate all such new upcoming critical events in the cockpit (and we can't), we would still have a fundamental problem of training

priorities. Would you rather train your pilots on numerous extremely rare events or routine problems they encounter all the time? Moreover, for training to be efficient it must be repeated enough or put into practice in real life to be profitable. That won't be the case for rare events. The training-over-duty ratio must remain realistic.

Another way to deal with this could be to prepare pilots for adversity by enhancing their coping capacity for the unknown. Alas coping capacity is hardly teachable – it appears to be an experience-based ability. At this point we have to admit the future is looking grim but let's consider that, today, human-machine interfaces are mostly designed for 'within envelope' operations. There is room for improvement. AI, itself a model of opacity, has motivated the Defense Advanced Research Projects Agency to fund research that would make it "[self]-explainable". Such AI would complement its propositions with clear elements that would make them graspable to humans, so they mostly wouldn't doubt them.

Yet using complex systems without understanding them is putting your faith in magic. It can work and has in the past; there has always been complex technology around compared to the level of education (think electricity or the internet). But the satisfaction with such magic is acceptable only if it never fails or if it represents a last chance option (for example the panic button – a better than nothing solution).

One solution is to get outside help to deal with it. Most of us are already doing it: remember the last setting up of that new oversized connected TV, with your entire pre-existing tech (box, wi-fi, media player, etc.). You weren't able to do it yourself, so you looked it up on YouTube, found the tutorial, followed it step-by-step and there you were, all done and feeling like a hacker. But conditions were optimal; there was no threat, no time pressure, no risk or critical consequences in



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We need an AI (machine learning based) system to explain complexity when it arises at cockpit level.

case of failure. Our pilots can't (yet) do the same. We need another kind of outside help; we need intelligent assistance (IA).

We need an AI (machine learning based) system to explain complexity when it arises at cockpit level. We have to develop a mediation interface, between technology and its users, dedicated to explain and accompany critical situations – an interpreter of sorts, for puzzled humans, capable of explaining in a reasonable and understandable way those complex

situations. Just like when we were children and that very good teacher could make us understand with accessible words what was most complicated.

It's our future, the choice is ours: endure without understanding (like children facing fallible magic) or develop the intelligent assistance between human beings and the almighty complexity, to safeguard our capacity for control.

KEY TECHNICAL AND SOCIOTECHNICAL CHALLENGES

8. Single pilot operations – more questions than answers?

Written by **Professor Don Harris, Coventry University**

The air transport industry is not exceptionally profitable. The principal impetus for the development of single pilot operations was originally financial but in the longer term there is likely to be a shortage of commercial pilots coupled with an increasing demand for air transport. For a medium-sized two pilot airliner, the flight deck represents 67% of crew costs. The International Air Transport Association estimated (pre-COVID-19) that post tax profits in 2017 averaged just \$7.54/passenger. Airbus has projected the size of the passenger fleet will more than double to over 31,000

aircraft within 20 years; 69% of these will be single aisle passenger aircraft or small jet freighters. Another 5,000 aircraft, of between 20 and 100 seats, will be required to serve regional requirements.

Resolving these conflicting demands will not be easy. However, single pilot operations may provide another option for reducing costs and averting a pilot shortfall. Such an aircraft is well suited to short-range, price sensitive operations. As part of the FAA Reauthorization Act of 2018 it was proposed that there was “a review of FAA research and development





Everything must be designed around the lone pilot, but it would be wrong to think of its development as solely a problem in flight deck design.

activities in support of single-piloted cargo aircraft assisted with remote piloting and computer piloting". Such a change in legislation may pave the way for the much larger step towards single pilot passenger operations.

Human factors considerations are the main driver. Everything must be designed around the lone pilot but it would be wrong to think of its development as solely a problem in flight deck design. Work in the UK funded by InnovateUK and major avionics manufacturers is underway developing a range of support technologies for single pilot operations. These range from design of new display systems to novel control interfaces. Various technological approaches are being explored. Some centre on the development of increased levels of on board automation, others adopt a more technologically cautious approach, using distributed systems-based design philosophy or borrowing technology from fast jet military aircraft and unmanned aviation systems.

However, the main barrier to the development of this aircraft is not the technology per se but deploying it appropriately. Building the aircraft is half the challenge, the remainder concerns ensuring that it can be operated by an airline. This raises a set of non-technology issues. A redistribution of tasks between aircraft and ground support brings up substantial questions: how many people will be required on the ground to support the pilot? Who does what? What experience and qualifications would be required for these personnel? Training facilities for the ground support personnel and pilots will be needed, increasing the complexity of provision. An air or ground based operation will need training as an integrated system. A fundamental human factors question is simply who are you designing the flight deck for – younger or more experienced pilots? The co-pilot role ceases to exist in a single pilot concept, so how do commercial pilots gain the experience to operate safely as captains? An aircraft commander is responsible for making operational safety decisions, crew management and passenger situations, as well as flying. These are but a few of the operational issues.

Although not directly related to its design, these issues determine the viability of the concept. Overall operating costs need to be reduced by using a single pilot and not simply be redistributed across the airline. Single pilot aircraft must be able to operate alongside conventional aircraft in the airspace without special considerations. More importantly than anything else, single pilot aircraft must demonstrate at least an equivalent level of safety to multicrew airliners.

9. The changing social landscape of commercial aviation

Written by **Siân Blanchard, Avior Risk Consulting**

In the coming decades, the future flight crew will be more diverse in ways such as family circumstances, gender identification and age, with more pilots choosing aviation as a second career. A more diverse workforce means that their needs will be different. Airlines must adapt, recognising that flight crew will demand greater organisational support to accommodate commitments outside of work, such as raising a family, living with managed illnesses, caring for relatives or spouses, or pursuing other work or personal interests. There are higher societal expectations about healthcare, career variety and development, adaptable and flexible working practices, flexible employment contracts, mentoring and leadership. These changes are not unique to civil aviation – they reflect broader societal changes and expectations. Successful airlines will appreciate these changes and will make preparations to compete for the best people and to sustain them through productive careers.

These societal changes are already being reflected in regulatory changes, through additional expectations on airlines to create healthy and sustainable working practices, notably the recent European Union Aviation Safety Agency (EASA) regulations on pilot mental health, peer support and flight time limitations. This trend is likely to continue. There is an opportunity for psychology and human factors to offer insights to organisations for integrating these requirements into a holistic approach that views the human as a whole and enables sustainable careers.

Commercial airlines sometimes manage welfare issues in a fragmented manner. This makes the management of these risks cumbersome, inefficient and inflexible to changing circumstances. For example, fatigue risk

is generally managed independently from other safety risks. Flight time limitations may become interpreted as targets, rather than limits close to the safety margin of what is acceptable.

The limitations of fragmented wellbeing approaches may also be seen in a proliferation of programmes to foster staff mindfulness at the same time as implementing measures that erode the fundamental social support systems at work. For example, an emerging practice in some airlines is to introduce on board briefings. While this may save commuting time, it has been described by some as removing contact with the crew room which can be an important social hub that the flight crew value. This is more than just creating stable rosters and keeping staff content – it's about creating sustainable careers and resilient organisations.

Aviation organisations have an obligation to build the systems that support individuals to optimise resilience. The new European Union Aviation Safety Agency rules on pilot mental fitness promote a peer support programme that is accessible to all flight crew members, that must be integrated into a non-punitive and just organisational culture, and that should be linked to the existing organisational safety management system. The regulations promote a systemic approach but operators rushing to implement the rules before the deadline, or working with limited resources, may be tempted to interpret the rules narrowly. Operators who wrongly believe the risk to be managed lies only with a small set of unidentified mentally ill or potentially suicidal pilots who simply need to be found and removed from service, will always be behind the curve and continue to be reactive to individual cases. They fail to realise that everyone can



be vulnerable to such issues, and in doing so will miss a bigger opportunity to raise the standards of health and wellbeing in the airline for the whole workforce.

Managing welfare properly means creating a holistic and coherent framework. In order to enhance the health and resilience of the workforce, organisations must do more than focus on individuals. It's simply not good enough to pay lip-service to employee wellbeing and engagement through superficial gestures such as subsidised gym memberships or fruit in the office.

An holistic, sustainable model of welfare requires thinking differently to create the systems and working environment that allows flight crew and other important roles to thrive in long, productive careers. A healthier workforce is less prone to errors and incidents, less likely to be away from work, and above all, more able to play their part in the team. Getting smarter at managing risk in this key area is vital to delivering a sustainable growth strategy.

KEY TECHNICAL AND SOCIOTECHNICAL CHALLENGES

10. Will we control the automation or will it control us?

Written by **Tamsyn Edwards, San Jose State Research Foundation at NASA**

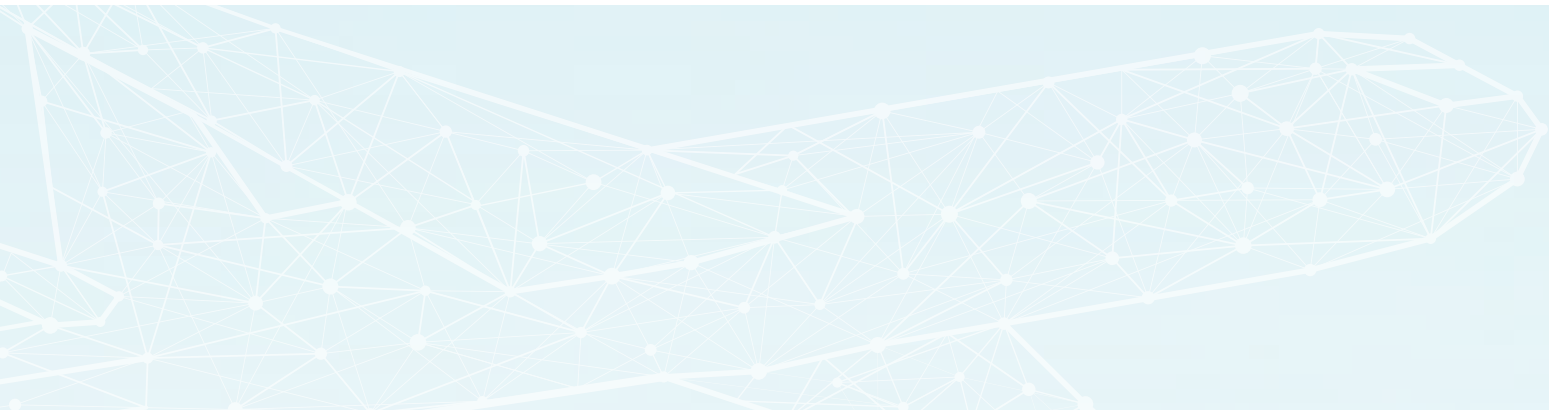
The purpose of air traffic control (ATC) is to provide a safe and efficient service for all air traffic. Since its inception, ATC has evolved in response to user needs, achieving exceptionally high standards of safety in a context of shifting complexity and density of air traffic operations. However, predicted changes in societal demands, technological advancements and airspace user needs create new challenges as we look to the mid and far term.

First, a growing number of industries are expanding into the aviation domain. Radical growth and diversification of non-traditional traffic is expected.

One example of this is the predicted increased utilisation of high altitude airspace (above 60,000ft) for diverse operations such as long distance weather balloons, supersonic aircraft and high flying commercial aircraft. Traffic will need to fly through lower altitude controlled airspace, however, creating an integration challenge for air traffic controllers (ATCOs) to manage traffic with widely varying performance profiles in the same airspace.

A second challenge is urban air mobility, in which small, passenger-carrying aircraft (e.g. sky taxis or





PAVs), will share airspace with traditional traffic, as well as drones. Current visions suggest that new entrant traffic will be managed independently of the traditional ATC system by third party organisations as part of a wider distributed system. Initially, human operators will assume traffic management responsibilities, though in the far term autonomous air traffic control is envisaged. Essentially, two different systems of traffic management may operate within the same airspace. All of this will occur against a predicted year-on-year growth of 'traditional' commercial traffic. To do this safely requires the identification and mitigation of workload drivers for ATCOs, clear function allocation between ATCOs and third-party organisations (especially concerning management of off-nominal events), and provision of new tools for ATCOs.

A majority of the predicted progressions focus on advanced automation to support service provision. One of the most fundamental changes proposed is the use of trajectory based operations (TBO), predicted to be fully realised in the mid to far term timeframe. TBO envisions that aircraft will fly prenegotiated trajectories that are managed during flight via time constraints, generating a shift from manual, tactical ATC to more automated, strategic traffic management. TBO aims to reduce ATCO workload and enhance system efficiency by making use of narrower tolerances.

Human factors will have a significant role in supporting ATC system safety in a context of growing automation, as well as the introduction of AI. Issues including automation transparency and reliability are key concerns, as are changes to the ATCO's role. There may be a need for a completely new role to supervise the automation or the AI, whether for security purposes

in case of attacks, or for safety reasons. While other sectors of aviation are considering significantly reduced human involvement such as pilotless aircraft, completely autonomous ATC carries huge risk and responsibility. Until autonomous ATC becomes a real operational possibility – if ever – the human must be able to fathom what local, regional or network-wide ATC automation is doing, and why. The why is the hard part. Proponents of AI do not guarantee their systems will be explainable.

Increased automation and reduced human involvement in ATC appeals to some because it has the potential to support increased traffic throughput and growing demand. However, the depth of expertise of the human operator, and the extent of the ATCO's contribution to system safety, are easy to overlook (until it's too late). An additional concern is the potential for deskilling human operators as a result of increased dependence on automation. Deskilling would have serious consequences for the ability of a controller to intervene in safety critical situations, as well as for overall system resilience, effectively removing a safety barrier. Human factors will be essential to ensure that there is not a loss of intangible skills and assets that currently keep the system safe.

ATC will continue to evolve to meet user demands. The application of human factors is critical to the successful advancement of the system, balancing forward progression with the maintenance of exceptional safety standards. At the moment, whether we control the automation or it controls us, is an open question. If we engage seriously with human factors in the evolution of system-wide air traffic management, it becomes a choice, one that is definitely under our control.

11. The human role in autonomous warfare

Written by **David McNeish and Darren Doyle, Defence Science and Technology Laboratory**

Lethal autonomous weapon systems have been the subject of heated debate at the United Nations in Geneva since 2017. For many, these systems conjure up images of uncontrollable killer robots stalking the battlefield. The reality is more complex. The UK government emphasises that “weapons will always be under human control”. Indeed, whether or not humans use sophisticated technological tools, they are ultimately held legally accountable for the use of force. Such accountability cannot be delegated to tools, however intelligent they may be. The question is, what does an ‘autonomous system under human control’ look like in practice?

From a military operational perspective, success is not only dependent on technical advances but upon how this technology is used. The UK describes this perspective as human-machine teaming, an approach which recognises that the integration of humans and machines with their relative strengths and weaknesses is the key to military success.

A human finger on the trigger for every use of force might seem like the most sensible answer – a human pulled the trigger therefore it must be under human control. This approach breaks down however, when you examine the way in which humans are currently involved in the military targeting process. Conventional air operations are highly distributed in terms of the nature of control between people and over time. Some have argued that solely relying on an operator making decisions in the heat of the moment, as a panacea for human control, is not always the safest approach as it means putting all your faith in a single defence against failure, rather than considering how multiple layers of defences may interact.

One thing is certain: context matters. The nature of the decisions or actions being replaced or influenced by autonomous systems must be considered – the OODA model (observe, orient, decide and act) is

one such approach. The task and the environment can also have major implications for how control is implemented. For example, a preplanned targeting activity against a known objective, versus self-defence, might require different forms of control. Equally, the operational environment, including its complexity and time constraints, may have an impact. As the time available to make decisions decreases, the level of risk associated with dependence on a human operator as the sole means of control may increase.

Past research indicates that supervisory control of automated systems can lead to both opportunities and risks depending on how it’s done. A lack of sufficient task familiarisation and feedback can lead to alienation of the human supervisor, with a range of likely negative outcomes. Another key human factors consideration relates to predictability and reliability – namely whether you can build a robust mental model of the system. For AI-based systems, the growing field of explainable AI is particularly relevant, as it seeks to provide justification for individual outputs, an understanding of how the system works in general including its capabilities and limitations and the ability to accurately predict what it would do given certain conditions.

The term ‘operational constraints’ refocuses our attention away from the point of pulling the trigger and onto those control measures which could be put in place beforehand. These might include constraining the types of targets that the system can engage, the environments in which it can operate, how long it can operate for, and the geographic area within which it can operate.

Finally, it’s important to consider not just how, but also when, human control is exercised. Human responsibility for the use of force is not confined to an individual operator but extends across the lifecycle of a weapon system. This lifecycle approach suggests



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The trend towards unmanned and remotely piloted aircraft within military aviation suggests an appetite for increased autonomy within future air systems.

control measures and processes throughout the design, development, test and evaluation, training, deployment, use, and even after-action evaluation of a weapon system.

The trend towards unmanned and remotely piloted aircraft within military aviation suggests an appetite for increased autonomy within future air systems. If so, then the questions in the minds of those designing future air systems are likely to include the following: how can the benefits of these emerging technologies be realised whilst working within a

human-machine teaming paradigm? What decisions should a pilot or operator be involved in and how? In what circumstances should an autonomous system be deployed, and what type of supervision might it require? What type of interaction must humans have with a machine to ensure they are in control? There is no one size fits all solution.

Human factors professionals, armed with these insights, must help ensure that future air systems are subject to the right type of human control, rather than the illusion of control.

KEY TECHNICAL AND SOCIOTECHNICAL CHALLENGES

12. Future training

Written by **Alison Heminsley, BAE Systems**

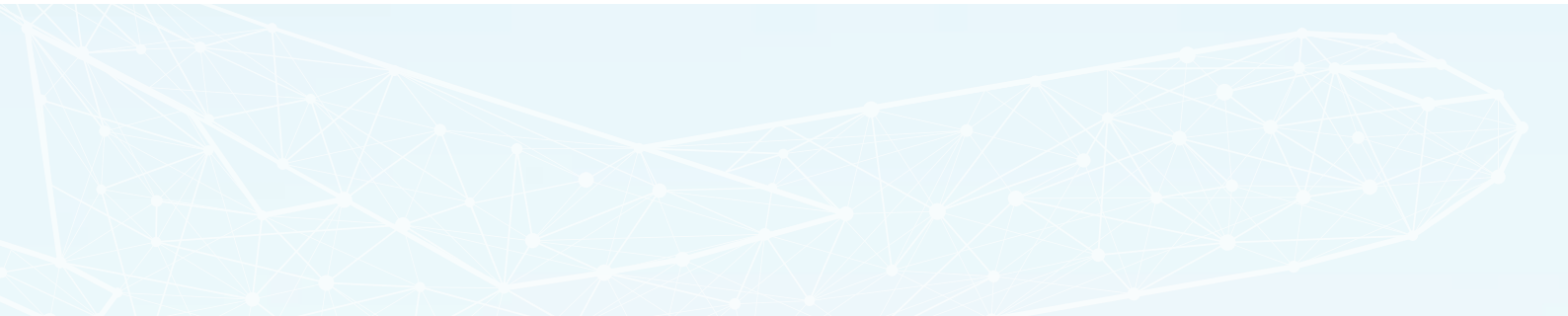
Ensuring that future aircrew and ground crew have the knowledge, skills and experience to undertake future aviation roles and improve safety will create new human factors challenges over the next few decades. Several concurrent factors associated with effectiveness and affordability create both risks and opportunities that will need to be addressed.

In civil aviation, in the longer term, there will be an anticipated shortage of pilots due to growing demand in air transport. A similar shortage will occur globally with respect to military pilots due to reduced capacity in the training pipeline. Training approaches will be required to sustain the numbers of qualified pilots in an affordable manner whilst ensuring safety. This

shortage will not only impact operational aircrew but also impact the availability of aircrew instructors. The shortage of pilots, coupled with a drive to reduce costs, will make single pilot operations the norm in both civil and military aviation. In military aviation, we're also likely to see the demise of twin seat training aircraft resulting in an increased need to use synthetic devices for training.

The next generation of prospective pilots have grown up immersed in technology and will have different expectations and approaches to learning. Portable digital technologies will increasingly be used to deliver training whether through virtual reality and gamification or electronic applications.





This will enable training to be undertaken at any time in any place at the convenience of the trainee. It will also create the need for automated trainee performance monitoring systems, providing real time evidence to assess progress and adapt the training provision to meet individual learning requirements and preferences. These systems, for example eye tracking devices and pilot workload monitoring devices, will provide both the trainee and instructor with increased amounts of targeted information for use in training debriefs, shortening the timescale for achieving desired levels of performance. With the continuous upgrade of systems through life, pilots and ground crew will also require timely and convenient retraining throughout their careers.

In the military sector, the increasing use of synthetic devices for the provision of training present certain unique opportunities. Firstly, the devices will offer training at a significantly reduced cost while reducing the environmental impact of live flying. A pilot of a military aircraft will spend most of their career training for operational events as opposed to conducting them.

Military synthetic devices also provide the ability to participate in high risk and complex integrated battlespace training events in a safe and secure environment, something that may be impossible to perform in reality. Secure high speed networks with real time communication between networked training assets will allow aircrew to take part in complex coordinated training, with participants undertaking individual training objectives. It will also support training for rare events which may not easily be encountered in live flying.

What then are the human factors opportunities and challenges that arise? The first is not new. Human factors must continue to develop valid and reliable measures of training effectiveness for use in evidence-based training, for training performance feedback and

for the customisation of training for individuals. Human factors can also be used to evaluate new training technologies to ensure that competence is retained for the expected time period, so that in swapping methods of training we have not eroded long term competency. Critical to the success of the endeavour will be to accelerate programmes of work with respect to how much live flying will still be required and to determine the parts of the training syllabus in which it's critical.

The effect of reduced live flying on maintainer training should also be noted: how will we train and retain maintainer competency when there are a reduced number of assets flying, and how will we ensure that this training is appropriate for maintenance in both hangar and frontline operations settings? Moreover, the role of the maintainer will evolve as increased use of autonomous systems, prognostics and analytics becomes the norm.

As well as use of synthetic training in commercial and military fields, it's likely to spread to the private sector, in particular PAVs, allowing PAV pilots to achieve basic or more advanced levels of competence, with skills and knowledge of how to handle unusual and potentially dangerous situations.

Although the focus here is on cockpit training, synthetic training at this level of fidelity offers another potential advantage to enhancing the overall resilience of the aviation system, via its use in system of systems training. For example, it may be useful for civil or military air traffic controllers to experience and understand the impact of high-energy manoeuvres (for example, a 'go-around' or a severe wake turbulence event in civil, or defence moves in military), to understand and even 'feel' the human impact. As aviation operations become ever more interconnected at the same time as jobs become more fragmented, achieving such understanding will enhance safety.

13. Innovation and regulation

Written by [Emma Simpson, UK CAA](#)

What will the future aviation landscape look like? What is it that we're trying to regulate? An example within the mid term future is that of smart cities – cities served by a variety of air and ground vehicles, both manned and unmanned, operated electrically, seamlessly integrated, sharing data on interoperable platforms, using AI capabilities to detect conflicting obstacles/airspace users and people. In this environment, packages and food are delivered by drone, bringing convenience and customer service, along with different noise profiles and considerations for privacy. Commuters can choose urban air mobility for smart city travel but is this available for all, or just the preserve of the elite? Consumers have ever more flexibility and choice in how to book travel but may be unknowingly subject to personalised pricing algorithms. Airports cater for all demographics of passenger, tackling hidden disabilities and the mobility issues of an ageing population, with increased automation enabling smoother and faster movement through airports but with a reduction in the empathy that's unique to human contact.

Innovation is coming and as a regulator, the public interest is best served by being ready. Maximising regulatory readiness in innovation has a two-fold purpose. Firstly, it enables innovation to be embraced and enabled from a growth perspective, helping innovators understand the aviation regulatory landscape and enabling testing and trialling in a safe space to create a pool of shared knowledge within the innovation ecosystem. Secondly, it's about being able to work with industry from the outset, understanding the implications of new technology, the human-machine interfaces, what risks may be introduced and how these are mitigated, and translating this to core regulatory teams so that regulations and guidance are in place for public protection in advance of such innovations reaching the market.

The history of human factors teems with examples of the criticality of the human in the loop in complex systems (for example, the transition to the 'glass cockpit'), and perhaps never more so than during transitions from human operations to autonomy. When innovation presents a new context, a new way of connecting operators with machines and connecting machines with their surrounding environment, human factors presents the keystone upon which regulators can build a safe bridge. Within smart cities for example, urban air mobility (UAM) presents a new end-to-end experience for the consumer. However, from a regulatory perspective it is not just about the flight from A to B, or purely the technology – it involves how the tickets are sold, what consumer protection there is, the security considerations, as well as the airworthiness of the vehicle, the parameters of the operating environment and the competency of the flying taxi pilot and/or autonomous system.

Some UAM business models are predicated on humans being in control in the cockpit of these vehicles for years to come but with highly automated systems that require different skill sets for human operators than those of traditional pilots. Increasing aerial vehicle density presents a new challenge for regulators in assessing what good looks like in terms of the skills and competency required to safely operate or monitor a highly automated system. If the skill requirements are too low, there may be insufficient expertise to respond in an unusual circumstance, if they are too high, boredom may become an issue.

Other UAM models are predicated on going straight to full autonomy (no human intervention required), as the transition of removing the human from the loop is perceived to be more complex than starting with full autonomy. In this context, is the wider infrastructure set up to support this? At some point the extent of full autonomy in one part of the



ecosystem hits its boundaries, and the operation becomes part of the wider sociotechnical system, requiring human considerations at different junctures. Additionally, it requires human input to design and assess the capability of the machine in the first place. Human factors considerations will be critical in understanding the behaviour of the machine, the range of possible outcomes from self-learning or intelligent software, as well as a whole range of ethical and societal implications. Perhaps we can utilise our years of experience in assessing human performance, behaviour, fatigue, etc., to create a 'medical' for a machine that is futureproof and fit for purpose.

Whilst we cannot control the inexorable pace of change, we can formulate regulation from a systems perspective. We can build more agile frameworks and regulatory operating models that can anticipate and adapt to the changing environment. As the technology evolves, so does the manner in which we regulate, and in the absence of historic data we must use our experience and knowledge in a different way. In this unprecedented confluence of technological and social advance within aviation, the mindset of the regulator must remain flexible, with human factors at the fore.

14. Reducing vulnerability to human error: a total systems approach

Written by **Hazel Courteney, State Safety Global**


Aircraft manufacturers cannot be expected to prevent all human errors or be responsible for any possible incorrect action by a maintenance engineer. This would be impossible. But just as we expect them to make a professional assessment of likely technical failures based on experience and available data, so it can be with human error.

There are plenty of reported data of components being installed incorrectly or incompletely, or of a similar but incorrect part or treatment being used, or a flaw missed during inspection. These are foreseeable errors – data and the experience of maintenance engineers provide an indication of how likely it might be. It's not necessary to anticipate that a maintenance engineer will do

something ridiculous. So, how do we assure the safety of such aircraft from human error?

Complex functions are performed by systems, typically a combination of technology and the humans who operate and maintain the equipment, for example, aircraft. We know that technology can occasionally malfunction. We make provision for this during the design process with well-established methods such as functional hazard analysis to identify safety critical items and failure modes and effects analysis (FMEA) to assess what could go wrong, how likely that is, how it would be detected and what the safety consequences could be. These are part of the documented system safety assessment (SSA). If the safety consequences are serious, they must





happen very rarely, if the consequences are mild, they can be tolerated more frequently.

We also know that human error is the most common causal factor identified in aviation accidents. Equipment design affects both the probability and the safety consequences of error. Flight deck design has already embedded some human factors approaches for pilots, and maintainability is considered throughout the aircraft design. However, what is missing is a systematic, documented approach to achieve a standardised level of safety protection from human error during maintenance.

Inspired by the engineering SSA, a human hazard assessment (HHA) technique has been developed using existing analysis to identify the safety critical maintenance tasks and then using an adaptation of FMEA – a Human Error Modes and Effects Analysis – to systematically assess how individual tasks could go wrong, the detection opportunities, the potential risk created, and the type of mitigation. HHA provides a technique that fits well into existing design processes and provides design engineers with what they need, that is, a way to identify specifically where they need additional human factors effort and crucially, how much is enough. The process provides confidence that the safety critical tasks have been systematically examined for vulnerability to human error and any apparent issues assessed and resolved. This can complement the engineering assessment with assessment of safety risks from the human element and make the SSA a true system safety assessment. Recent accident experience has shown the dangers of not doing this. Human factors in design and maintainability considerations should no longer be there by exception. It must be mainstream.

The near future should continue to evolve total system considerations, for example:

- Error tolerance analysis for system design life cycle elements that already exist but are not yet analysed (for example, HHA for production).
- Human factors principles that are known but not yet embedded (a maximum false alarm rate to avoid negative training impact).
- Reliability and safety standards for rotorcraft that are comparable to commercial aeroplanes.

The approach can also be applied to new system entrants and architectures:

- For personal aerial transport, many if not most of which will be of the rotorcraft variety, aircraft design that is simple and consistent with the expectations and capability of public users.
- Coordinated development with other system elements such as ATC.
- Flexibility to dynamically allocate functions between elements of the system (remote electronic maintenance during flight, as well as controlled or self-separation pilot options).
- The human factors of remotely controlled systems (pilotless passenger transport).

Aviation today – and increasingly tomorrow – is more than ever a system-of-systems. What is needed is to move beyond SSA to a Total Systems Approach, which addresses all the system elements in their interactions and across their complete life cycle, and which fully integrates human factors assurance methods and principles. Otherwise the future will arrive before we are even close to being ready.

15. The future of safety cases

Written by [Christian Fairburn, Reliable Interaction](#)

Faced with highly visible step changes in aviation transport, including single pilot, remotely piloted and autonomous aircraft, and operational situations where the humans in control may not be licensed pilots, the public are likely to demand clarity when it comes to safety. On what basis is it considered safe for me to get in this pilotless vehicle? On what basis have authorities allowed this vehicle or these people to fly over my house and children? A public culture with an allergy to experts does not sit well with safety engineering, which by definition is an open loop industry with an emphasis on prediction, subject matter expert judgement and peer review. The basis for safety will need to be communicable to a diverse target audience, making clear the way in which responsibilities and accountabilities have been allocated.

Even if all the future platforms in an aviation system-of-systems may be able to argue tolerable risk on their own terms, what about the aggregate? If we're to anticipate and pre-empt the potential for adverse emergent properties in a complex, tightly coupled and diverse aviation domain, we're likely to need tools and techniques that can help us deal better and more explicitly with residual risk. There is scope for undesirable interaction of residual risk. How will ownership of risk be managed? How will residual risk be shared between all the stakeholders and between the different interacting systems or even the decision making autonomous system itself? Adopting a sufficiently sophisticated view will require safety cases to appreciate the dynamic real time nature of residual risk. This could become more important since the user of the future system may be the consumer. Understanding their view of risk and system safety will become part of the safety case.

This could lead to proactive engineered safeguards and more real time contextualised safety assessment. Is this vehicle in its current state sufficiently safe to fly in this

way, for this purpose, in this environment, with these other vehicles around it? There will be safety benefit if air vehicles themselves can contain aspects of technology devoted to real time residual risk analysis. Consumers commanding take off or preferring a certain flightpath will have to be open to the possibility of the technology deciding that it isn't such a good idea right now.

Carrying this theme forward, safety cases of the future will need to become stronger in terms of explicit prediction, analysis and assurance of violation related risk. Non-professional public users will be increasingly inventive in this area and, at least initially, they may be more ignorant or insufficiently cautious in relation to consequence. If issues of accountability and responsibility, and the rationale behind user procedures are not communicated effectively, users of future technologies may make bad safety-related choices. Safety cases will in the future need to assess violations in ways analogous to what is routinely done for human error, accounting for target user risk perception. Autonomous technologies by nature have potential to become more like error makers themselves. Working-as-designed artificially intelligent systems may mis-assess situations, offering the possibility of being accused of making a mistake in a way that is not within the scope of current technologies. Importantly, self-learning technologies could also become violators if we let them.

Where and how will tomorrow's accidents arise? Probably not as expected! Greater analytical attention will be directed where compelling, salient scope for risk is perceived. Designers and safety professionals like everyone else will be subject to the human biases. The tricky part will be to identify difficult to conceive complex chains and to recognise the reality of situations that initially appear misleadingly benign.

There will be scope and temptation for tool-based assistance, even automated or artificial intelligence



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Tomorrow's safety cases will benefit from a system-of-systems approach where humans are an integral consideration, both as developers and assessors of the safety case, and considerations within it.

driven safety analysis and safety case generation. It will be important not to automate safety to a degree which results in humans becoming out of the loop. We do not want the patterns previously observed front of house in aviation to be repeated behind the scenes in future design and safety engineering processes. This means we must avoid the human participants in the safety case struggling to understand what the data mean, what it is they have discovered, and the core assumptions on which safety beliefs and assertions are founded. There is great scope for human factors involvement here.

Tomorrow's safety cases will benefit from a system-of-systems approach where humans are an integral consideration, both as developers and assessors of the safety case, and considerations within it. This will require changes in one area of the aviation architecture being recognised and responded to in others. Finally, there will be a need for more compelling confidence arguments to be made in relation to the absence of human error during system and safety case design, implementation and documentation processes. These are the areas that will be driving the future's safety outcomes.



THE WAY FORWARD

The way forward: five human factors destinations

The foregoing thought leader pieces have highlighted the key human performance challenges facing civil and military aviation, from coping with AI, to ensuring mental health and wellbeing in the workforce, to ethical considerations in future warfare. Individually, each of these articles reinforce the need for aviation and human factors to continue to work together. Taken collectively, however, they suggest aviation and human factors are at a crossroads, and call for a deeper working partnership.

Aviation is going to change dramatically during this decade. For many years people have talked about what needs to be done by 2020, and beyond. Well, 2020 is here. In this decade we will see the rise of urban air mobility, with drones and sky taxis above and around our cities. Single pilot operations, most likely beginning with cargo aircraft but progressing to airliners, is likely to come to pass before 2030. AI, probably first in the form of intelligent assistance, will appear before the end of the decade, and will not only affect the flight deck but also air traffic and airport operations.

Formerly, aviation could proceed at a measured pace, with many years or even decades between major shifts in technology, ushering in new generations of aircraft type. This is no longer the case, as aviation is no longer spearheading the technological innovations it will come to rely upon, and new business entrants are arriving thick and fast, with regulators struggling to keep pace. Human factors must also accelerate its development and capability to support aviation.

Extending human factors' horizon

Human factors at its core is an applied discipline and works best when focusing on real, people-centred work systems. However, up until now it has often worked in a piecemeal fashion, being tasked to answer a particular issue, whether on training, a new cockpit display, a new air traffic controller interface design or a safety culture problem. This places human factors in both a reactive and passive mode. It's available when you need it. This may suffice with long design and development cycles, where there are many iterations and chances to detect and correct problems as they arise. But it will not work in an accelerated design and delivery environment.

Military aviation human factors, generally speaking, is better than civil aviation in this respect, with more fundamental research and development looking towards tomorrow's concerns. But in both civil and military aviation there is a need for a more concerted effort to harness human factors, to raise its game so that it can support the raft of innovations and their interactions – intended and otherwise – that will become aviation's 'new normal' in this decade.

Human factors is a systems thinking approach and since aviation is increasingly a system-of-systems, human factors will better meet aviation's needs, including coping with emergent issues not yet foreseen or planned if it supports aviation at a systems level, rather than piecemeal. The human and the technology need to be seen as interdependent – each supports the other to function effectively. This means funding human factors research and development workstreams at a macro, rather than micro, level, focusing on the key waypoints that will guide aviation through this decade. These destinations need to be mission-orientated, focused on the evolving needs of industry and society, deliverable by integrated, high quality human factors research programmes.

FIVE AVIATION HUMAN FACTORS DESTINATIONS

The key challenges facing aviation – not forgetting that these are also major opportunities to improve our society and defend our way of life – are both technological and social in nature. They can be grouped into the following five destinations.





1. Urban air mobility

This involves drones – whether used for delivery, surveillance, med-evac, or other purposes – sky taxis and personal vehicles. Human factors issues include:

- Interface design and training for drone operators, sky taxi drivers (on board and remote) and air traffic controllers
- Safely managing the complexity of highly dynamic operations in densely populated areas with a variety of aircraft platforms, users and business models
- Communications (cyber) security, safe management of failed or rogue vehicles
- A fall-back system in case of operational system-wide failure
- Understanding the needs of the various human operators and end users (including the passenger experience), as well as the wider urban population (for example, tolerance to noise, privacy issues, etc.).



2. Intelligent interfaces

This concerns new automation, augmented reality and artificial intelligence based interfaces, whether in the cockpit, the air traffic control centre or remote tower, or for the airport ground handler supervising robot-based operations. Human factors issues include:

- Intuitive and trustworthy interface design that also avoids startle response or 'automation surprise' when adverse or unusual events occur
- Adaptive automation based on biometric monitoring
- User interface models that optimise crew and system performance without leading to critical skill loss or complacency
- Explainable AI and optimised human-machine teaming
- New supervisory roles for monitoring of autonomous operations and recovery training and aids in case of system failures or perturbations (including cyber-attacks)
- Advanced simulation training for complex adverse events.

THE WAY FORWARD



3. Future flight crew

This is a stepwise evolution from reduced crew operations, to single pilot operations, to remote pilot operations (no pilot on board but the aircraft is still at least partly controlled by a pilot), to autonomous aircraft. 'Crew' here refers to the distributed human crew (both airborne and on the ground) ensuring safe flight. Human factors issues are wide ranging, involving:

- Procedures
- New training concepts and facilities (including training for a distributed operational system with new roles)
- Fall-back systems in case of pilot incapacitation
- Cockpit design
- Remote pilot training and interface design
- Biometric monitoring and adaptive automation or intelligent assistant support
- New air traffic management concepts and roles.



4. Future workforce

This destination concerns all aviation workers, not only those at the sharp end such as pilots and controllers, but also cabin crew, all ground-based personnel including airside and maintenance workers at airports, and engineers in airframe manufacturers and equipment suppliers. Human factors issues include:

- Maintaining the attractiveness of working in aviation
- Fatigue and wellbeing management
- Collaborative distributed teaming based on shared understanding of roles across traditional work interfaces
- Smarter training methods
- Managing the social, demographic and cultural factors in the working population that can affect performance
- A general focus on unlocking the potential of the workforce to maintain high standards of system performance and resilience.



5. Future governance

This refers to the way future systems will be regulated and managed at system level with respect to human factors and human error. Issues include:

- How to ensure sufficient safety culture at senior management levels and all levels of operations in the various business models for all airspace users, as well as in airframe manufacturers and suppliers
- How to encourage businesses not to focus purely on the 'bottom line' at the expense of safe design and operation, leading to more 'error-proof' design and maintenance
- Ensuring just culture across the aviation spectrum so that honest safety reporting and fast-response learning can take place
- Earlier integration of human factors into design processes
- Human hazard approaches that fit within systems engineering and safety case methods
- Ensuring an appropriate level of human factors competence in key organisations, including regulators.

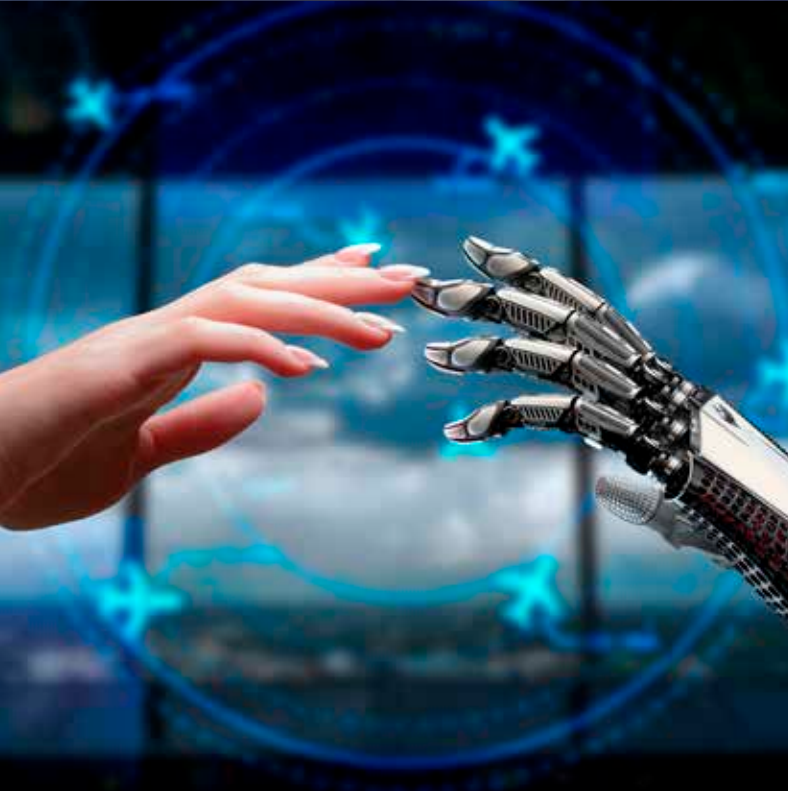


Reaching these destinations will clearly require a mixture of traditional and new human factors thinking but above all will require a deeper working partnership between aviation and human factors.

These destinations require us all to do more. We need to better understand them, to map them out, and then plot the journeys to get there in a way that will enable human-technology partnerships to deliver a safe and integrated high performance aviation system-of-systems.

The journey to these destinations requires certain shifts in our collective mind-sets; there is some baggage we should leave behind. First, human factors research is clearly essential but it must focus on application in realistic operational and regulatory contexts. Second, regulatory approaches need to be agile but also systemic, which is likely to require a non-traditional approach. Third, technology development needs to be more human-centric than it has been to date, considering how to integrate human capabilities for system success.

Reaching these destinations will clearly require a mixture of traditional and new human factors thinking but above all will require a deeper working partnership between aviation and human factors. The thought leader pieces in this white paper, when taken collectively, argue that the coming decade will be nothing short of a paradigm shift, a transition to next generation aviation which will change the way we use and think about aviation in both civil and military aviation domains. Aviation is on an uncharted and unprecedented journey. Human factors can help make it a safe and smooth one that delivers high performance to operators and end users alike, while maintaining a high level of commitment and wellbeing for all those working in the industry.



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