

## Introduction

In this INSIGHT paper the ATI explores the aerospace industry's journey towards single pilot operations. While reviewing the roles of technological automation and autonomy in the possible approaches to enabling the concept of a single pilot airliner to become operational, other factors are identified as more significant drivers. Economics, demand, the projected shortage of pilots and the potential impact on aviation training play a huge role in moving towards fewer flight crew. However, innovation and development in flight deck technology are integral to realising effective and safe single pilot operations and it is imperative that the human sits at the heart of the conversation around reducing the number of crew onboard.



## 12 THE SINGLE PILOT COMMERCIAL AIRCRAFT

## THE NEED FOR A SINGLE PILOT COMMERCIAL AIRCRAFT

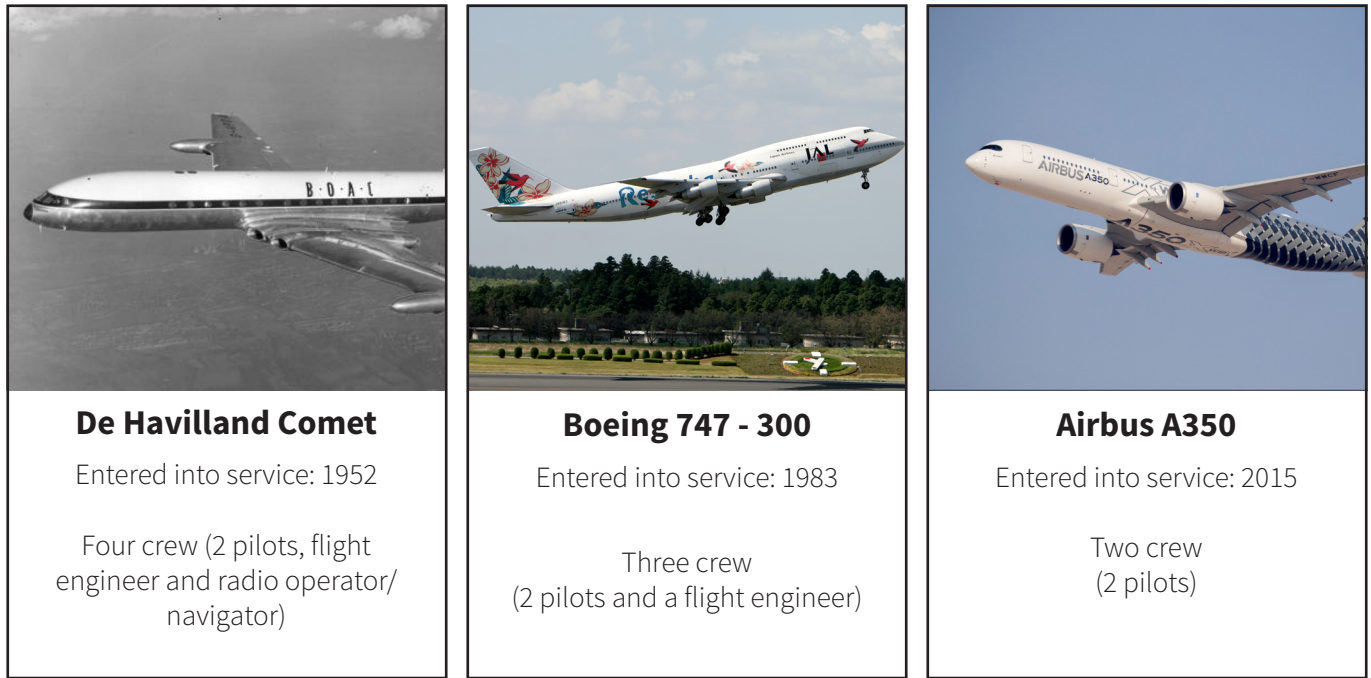
Most major aircraft manufacturers and avionics systems suppliers are developing the technology to support the introduction of single pilot airliners. Luiz Sergio Chiessi, Embraer Vice-President for airline market intelligence, has stated that they are looking to provide single pilot capability by 2020-25<sup>1,2</sup>. Other programmes have investigated the feasibility of using just a single member of flight deck crew in long-haul aircraft during the cruise phase (e.g. the European ACROSS project: Advanced Cockpit for the Reduction of Stress and Workload). Paul Eremenko, former Chief Technology Officer at Airbus has openly stated that the manufacturer is developing technologies that will allow a single pilot to fly an airliner<sup>3</sup>. In the UK work is being undertaken as part of the ATI-funded Future Flight Deck and Open Flight Deck programmes to determine the technology requirements and crewing strategies for a single crew airliner. However, Thomas Edwards, Director of Aeronautics at NASA Ames Research Center, has expressed the view that the single crew aircraft is only the beginning. He suggested ultimately that the issue is not about should single pilot operations be adopted, but 'is one pilot a logical stepping stone on the way to zero pilots?'<sup>4</sup>.

The development of single pilot flight decks will provide the economic and operational impetus for the development of a range of advanced technologies for implementation in the next generations of commercial aircraft, irrespective of how many crew are ultimately on board. In a single crew airliner, increased levels of sophisticated automation and/or autonomy will be necessary to reduce the demands on the pilot in times of high workload or to ultimately take control of the aircraft in the case of pilot incapacitation. To do this there needs to be the appropriate allocation of work between the pilot and the aircraft to ensure safe and efficient flight. Single crew aircraft flight decks will provide a catalyst for the development of a new range of human-centred technologies supporting new airline operational concepts. The human factors requirements will likely be the prime driver, not the hardware and software technologies.

### AUTOMATED Vs AUTONOMOUS SYSTEMS

**Automated** systems are deterministic. Automation refers to a number of related functions performed automatically. There is an assumption that the pilot initiates the automated sequence of actions and needs to take over once again at the end of the automated task sequence. The same inputs will always result in the same outputs.

**Autonomous** systems are non-deterministic. The equipment is capable of performing defined operations within certain parameters without human input or guidance. Unlike automated systems, autonomous systems have a set of adaptive, artificially-intelligence based capabilities that allow responses within particular boundaries that were not pre-programmed or anticipated in the design. As a result, the same inputs will not always result in the same outputs.



**Figure 1:** The progression of cockpit crew over time

The trend in flight deck design over the past half century has been one of progressive ‘de-crewing’. The common flight deck complement is now that of two pilots, but only 50 years ago, it was common for there to be five crew on the flight deck of an airliner. Now, just two pilots, with much increased levels of assistance from the aircraft, accomplish the same task. However, at the moment, by regulation and by law, two pilots is the current minimum flight crew complement for a large commercial aircraft. Nevertheless, there are signs that this may change in the future. In 2018 as part of the ‘FAA Reauthorization Act of 2018’ put in front of the US Congress, it was proposed that the ‘Administrator shall transmit a report to the Committee on Science, Space, and Technology of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate that describes... a review of FAA research and development activities in support of single-piloted cargo aircraft assisted with remote piloting and computer piloting’ (NB! this applies only to cargo aircraft)<sup>5</sup>. Such a change in legislation would clear the way for the introduction of a FAR/CS part 25 single pilot passenger aircraft, but initially in cargo operations.

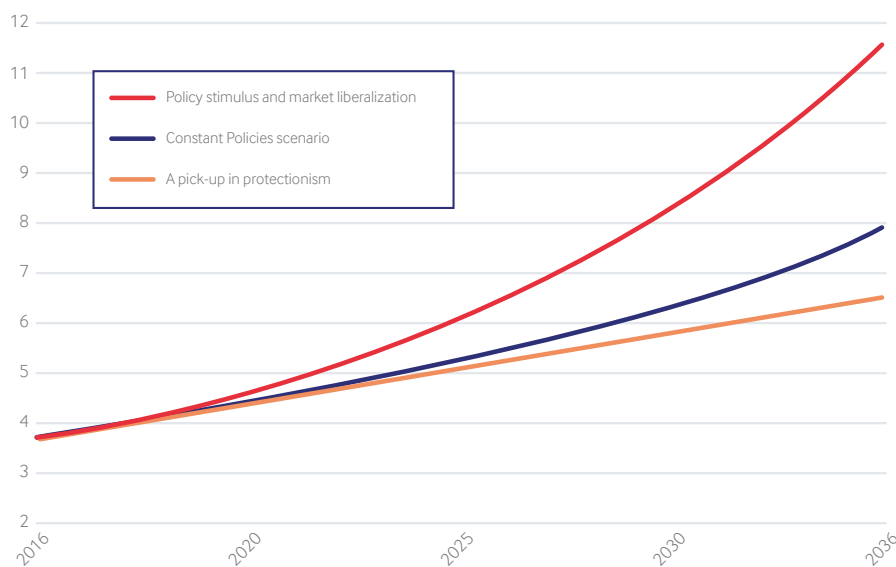
The greatest obstacle to the development of a large civil, single pilot aircraft is not the technology per se but applying the technology appropriately and developing the necessary automation and user interfaces. The human factors requirements are the main concern as everything must be designed around a single operator. However, rather than simply asking the question ‘can we design and operate an aircraft using only a single pilot’ it is also worth asking a related, but slightly different question: ‘why do we actually need two pilots?’ Removing the second pilot does not necessarily mean replacing their function (function allocation by substitution). There may be other ways of doing the job. It is essential not to fall into the ‘mechanical horse’ trap. If you want to travel faster and/or carry a heavier load, then making a mechanical horse is not the best way of achieving these aims. A different approach to solving the problem is required, for example designing and building a car. To avoid this pitfall a fundamental re-analysis of how things are currently done is required. But building a single crew aircraft is only half the challenge: the other half will be operating it in an airline context. This raises a further set of non-technology issues that will also need to be incorporated into the design of such an aircraft.



## Drivers for the Development of a Single Pilot Commercial Aircraft

Originally the main driver for single pilot operations was financial, but issues relating to a potential shortage of commercial pilots in the near future now play a major part.

The airtransport industry struggles with profitability, with constant downward demands on pricing and unpredictable, fluctuating fuel costs. The IATA (International Air Transport Association) report for the second half of 2016 shows that the average return fare in 2017 (before surcharges and tax) was \$351, down from \$407 in 2015, and it was actually 68% lower than in 1995. World-wide post tax profits have declined from \$9.89 (per passenger) in 2015, to \$7.54<sup>6</sup>. Airline personnel costs vary between about 11% of operating costs to nearly 25%, depending upon aircraft type, sector length and how much activity is outsourced: the crew themselves can represent up to 13% of operating costs (excluding fuel and propulsion). Halving the number of pilots has the potential to produce significant cost savings, especially in smaller regional aircraft operated on shorter, 'thinner' routes which may not be economically viable with higher capacity airliners. The direct operating costs attributable to flight deck crew rise as aircraft size decreases. It is estimated that for an airliner with two pilots and three cabin crew, the flight deck represents 67% of crew costs; this rises to around 76% in an aircraft with fewer than 100 seats which requires only two cabin crew.



**Figure 2:** Global passengers (billion, segment basis) [IATA]<sup>7</sup>

In its Global Market Forecast (GMF) 2018-2037<sup>8</sup>, Airbus projected that the world's passenger fleet will more than double to 48,000 in 20 years, with traffic growing at 4.4% per year, requiring 37,390 new passenger and freighter aircraft. Of those new aircraft, 76% will be what Airbus defines as the 'small' market segment, with capacity of up to 230 seats and a range of 3,000nm.

Boeing's estimate is higher – its Commercial Market Outlook 2019-2038<sup>9</sup> predicts a total global fleet of 50,660 by 2038, driven by traffic growth of 4.6%. Of the new deliveries supporting this growth, more than 78% will be single-aisle and regional jets.

What does this mean for pilot recruitment? The Airbus GMF is explicit: more than doubling the world fleet to 48,000 aircraft will result in a need for 540,000 new pilots.

For the US major inter-continental airlines, each aircraft requires (on average) 12.55 pilots; US national airlines typically require around 10.15 pilots per aircraft. US regional airlines, flying smaller aircraft require 8.17 pilots on average. Data from European low-cost operators suggest that these airlines require between 10-11 pilots per aircraft<sup>10,11</sup>. A single crew aircraft is particularly well suited to operations that are price sensitive, such as low-cost carriers; regional carriers and domestic air freight, where 75% of sectors are fewer than two hours.

There are signs of a rapidly developing shortage of airline pilots. Boeing calculate that between the years 2016-35, 112,000 new commercial pilots will be required in North America alone: 104,000 will be required in Europe and almost a quarter of a million in the Asia-Pacific region. Estimates of the size of the potential pilot shortfall vary. Some suggest that just in the US, between 2013-2031 there will be a shortfall of approximately 35,000 pilots<sup>12</sup>. The majority of this will be borne by the regional carriers operating smaller aircraft, as pilots migrate to job opportunities in the national and inter-continental operators. The cumulative shortfall of FAA certificated airmen in the US could approach 40,000 by 2035<sup>13</sup>. This will also have the effect of placing an increased demand on experienced airline pilots, pushing up personnel costs in what is already a price sensitive industry. The age profile of commercial pilots is also changing dramatically. It is projected that more than 42% of active US airline pilots at the biggest carriers will retire over the next 10 years. Numbers from the UK Civil Aviation Authority show a decline of 31% in total Commercial Pilot Licences (CPLs) issued in the four years between 2011 and 2015. Across the European Union as a whole, approximately 4,000 Commercial Pilot Licences (fixed wing) or Multi-Pilot Licences were issued in 2015. Using Boeing's figures, the actual requirement for new pilots in Europe is approaching 6,000 per annum.

Addressing such shortages has traditionally been seen as a pilot recruitment and training issue. However, being able to reduce the number of flight crew may provide a further option for reducing crew costs and helping to averting a pilot shortage.

## CHALLENGES FOR A SINGLE PILOT AIRLINER

The challenges for this type of aircraft are essentially the same as those for any aeroplane carrying passengers. It must be at least as safe as the equivalent existing multi-crew aircraft but from a pilot perspective it must also be more error tolerant. It must not impose higher levels of workload on its single pilot than those in the equivalent multi-crew aircraft, but it must promote the same level of pilot understanding and awareness of issues such as the airspace picture, tactical and strategic flight planning, aircraft system awareness and the flight envelope. It must be capable of operating in all categories of airspace and at all airports without requiring special assistance from Air Traffic Control (ATC). Many aspects of the current ATC-Air-pilot operational relationship are predicated on a two-person flight deck: single pilot types often require special handling to avoid overloading the crewmember with lengthy RT exchanges. However, SESAR, NEXTGEN and similar initiatives which will support increased connectivity have the potential to aid single pilot operations in the future in this respect via the use of non-voice ATC communication. From an airline's perspective its overall operating costs must ultimately be lower than that of a multi-crew aircraft. This includes acquisition, training, maintenance and operational support. Initial costs during the introduction of the technology may be increased but to be a viable proposition, these must ultimately be reduced. It is not just about the technology required to build the aircraft, it is about operating it.

However, the biggest challenge may have nothing to do with piloting the aircraft or the safety of its technology. Referring to pilotless commercial aircraft, John Hansman, Professor of Aeronautics and Astronautics at the Massachusetts Institute of Technology commented 'the issue has never been 'Could you automate an airplane and fly it autonomously?' The issue is "'Could you put paying customers in the back of that airplane?'"<sup>14</sup> The same basic question applies to single crew aircraft: will people pay to fly in it? Recent research on passenger opinion emerging from the USA has produced a resounding 'maybe...'. Younger passengers tend to be more accepting of the technology.

## APPROACHES TO DEVELOPING THE TECHNOLOGY

Various technological approaches are being explored for the development of a single pilot aircraft. Some focus upon the development of much increased levels of automation (for example, intelligent knowledge-based systems, autonomous systems and adaptive automation). Other approaches adopt a more technologically-cautious approach to using a large amount of on-board computing. These use a distributed systems-based design philosophy, utilising a great deal of extant technology derived from single seater military aircraft and UAS (Uninhabited Aviation Systems) technology.

It would be inappropriate to characterise these approaches as ‘either/or’ options: there is a great deal of commonality in the technologies to be developed and the operational challenges that airline operators would face. However, it is useful to characterise the approaches to developing a single crew aircraft in this way to illustrate the unique advantages and challenges faced by each technological strategy.

### Autonomous Systems Approach

Early approaches to the development of a single crew aircraft mostly utilised onboard technology: the emphasis was on adaptive automation and decision aids in the form of ‘intelligent co-pilots’ or ‘cockpit assistants’. Most of these systems were developed from military programmes where the pilots experienced an array of threats and were under periods of extremely high workload. These systems typically monitored the actions of the pilot comparing them against data from the position of the aeroplane, status of the onboard systems and external environmental factors. Algorithms were employed to determine if there was any difference between the expected and actual states.

These early systems providing pilot support were probably best characterised as ‘highly automated’ rather than having any real degree of machine intelligence/autonomy. Recent advances in autonomous technology now make this approach more viable for the development of a single pilot aircraft.

Where automation ends, and autonomy begins is a moot point. The UK MoD Joint Doctrine Notice (JDN) defines an autonomous system as follows:

*An autonomous system is capable of understanding higher level intent and direction. From this understanding and its perception of its environment, such a system is able to take appropriate action to bring about a desired state.*

*It is capable of deciding a course of action, from a number of alternatives, without depending on human oversight and control, although these may still be present. Although the overall activity of an autonomous unmanned aircraft will be predictable, individual actions may not be. (JDN 3/10)<sup>15</sup>*

Automation comprises sets of tasks, which may be extensive, complex and branching, requiring little input once initiated. However, these are well-defined, rule-based tasks with predetermined responses. Automated systems are deterministic. On the other hand, autonomous systems incorporate Artificial Intelligence (AI) and have adaptive capabilities allowing them to respond (within set bounds) to situations not anticipated and hence not pre-programmed. They have a degree of self-governance and self-directed behaviour which adapts to the context and learns. Unlike automation, an autonomous system may exhibit emergent behaviours; it utilises feedback to learn and adapt, and as a result may subsequently respond differently at a later date to identical inputs. As such systems can respond to unanticipated situations (unlike a deterministic automated system) they can reduce cognitive workload and even replace human decision-makers. However, as a corollary, autonomous systems may also make errors in perception and judgment.

A variable (or semi-) autonomous system will vary the levels of authority it possesses as determined either by the human operators (who may be pilots) or the context of operation. For example, an aircraft collision avoidance system, in detecting an imminent collision, may be delegated authority for engaging emergency manoeuvres in situations where the human is incapacitated or unable respond in time. This approach encapsulates the nature of 'scalable autonomy'. The single pilot airliner is likely to be such a semi-autonomous system.

### Distributed Crewing Approach

The distributed crewing design approach utilises a great deal of extant technology. This design philosophy has been adopted by the UK Future Flight Deck and Open Flight Deck programmes and by NASA in the US for its single crew commercial aircraft concept. This concept regards the single crew aircraft as one part of a wider system consisting of several elements, comprising the aircraft itself (including pilot), and a ground-based component including a 'Second Pilot'/'Ground Pilot' support station (or a 'Super Dispatcher' in the NASA concept<sup>16</sup>); real-time engineering support and navigation/flight planning support facility. In this type of system, the co-pilot is not replaced by on-board automation or autonomy, they are displaced.

This approach is also commensurate with operating concepts in major airlines, where aircraft are supported on a 24/7 basis by dedicated personnel in an operations centre. The functions in these centres include scheduling of aircraft; real time monitoring of engineering data; support for in-flight re-routing, and coordination of ground-based resources. Major airlines often have engineers from the aircraft or engine manufacturers embedded within them. Rolls-Royce has recently opened its own dedicated engine services Airline Aircraft Availability Centre (shown below) from where it can remotely monitor aircraft using the latest generation of engines and provide real-time support to pilots and coordinate maintenance and repair. Staff in this Centre actually have access to more information concerning the health and performance of the engines than do the pilots.



The objective of providing ground support from network control centres is to provide fully integrated, multi-disciplinary support to the pilots, alleviating them of the routine paperwork and providing them with support during high-workload, non-normal and emergency operations. Providing a range of dedicated expertise enables better decisions and helps to anticipate and manage the impact of unplanned events. In the distributed crewing approach, this concept is extended to encompass actual piloting support, especially during critical phases of flight.

### Comparison of the Alternative Approaches

The autonomous systems design philosophy and the distributed crewing approach both offer different benefits and challenges for the development and operation of a single crew airliner.

Adopting the autonomous systems approach where the aircraft has a great deal of on-board technology means that the aircraft is much more self-reliant – less dependent upon ground support and hence there is greater scope for an overall reduction in personnel numbers across the airline required to operate the aircraft.

However, it presents a much more complex development problem. The aircraft must be straightforward to operate with much simplified and intuitive flight deck interfaces (which will also have the net benefits of helping to reduce training time, workload and the opportunity for error). A pilot monitoring system will be required to check the condition of the pilot (not just health, but also other factors such as stress, workload and fatigue). This aircraft will need high levels of autonomy, which will probably be the major thrust of any development programme. However, these higher levels of autonomy will pose challenging certification problems.

The distributed crewing approach poses a much easier development prospect as it uses a great deal of existing technology and operational concepts, hence will also be faster to market and potentially pose fewer certification challenges (however these should not be underestimated). The human factors issues are largely understood as a great many of the operational concepts (such as embedded engineers from airframe and engine manufactures; real time flight planning and navigation support) are already established in airline operations centres. The aircraft is also more likely to use deterministic, automated systems, so will be easier to demonstrate an equivalent level of safety to multi-crew airliners and hence make a safety case. The design, production and maintenance of its avionics systems are also understood.

However, such an aircraft would be much more reliant on ground support and high integrity, secure datalinks. The crew is now distributed across air and ground hence also less scope for reduction in operating costs. There may be less flexibility in operations and such a configuration may create complex organisational, training and licencing issues (new qualifications may be required for personnel manning the ground station elements of the system). Ultimately, the technology may be rapidly superseded by single crew aircraft using the autonomous systems approach. Nevertheless, such a distributed system may provide an essential stepping stone to the introduction of aircraft using autonomous systems to support the pilot. Work studying passenger attitudes has found that a single crew aircraft with this configuration was found to be more acceptable than an unmanned airliner.<sup>17</sup>

## THE ROLE OF THE HUMAN

The common theme between automated and autonomous systems is the need for the human to set the high-level goals and to monitor the system. It is a misconception, not helped by terms such as, 'unmanned', that there is no human involvement required. The modern flight deck, while possessing a high degree of automation, still requires a large degree of supervision and monitoring from the flight crew, and the pilots need to be able to intervene when external factors require changes to the initial plan for the flight. The same will be true of the single pilot airliner, irrespective of how the technology is implemented.

Even in systems with a lesser or greater degree of autonomy it is important to recognise that the role of the human is not only critical in terms of supervising the system, but also providing key inputs that improve the system outcome. The caveat here is that the automation and/or autonomy should be built around what the human is bad at (for example, tasks that require long periods of vigilance, mental fatigue, mental overload) and also what the human is good at (for example, tactical decision making) – not just the former.

The three main human issues that need to be addressed for single pilot operations are:  
workload, system and flight management;  
tactical and strategic flight planning;  
and the avoidance of error.



The design of the aircraft flight deck should not simply impose workload on the pilot. Certainly, a poorly designed flight deck increases pilot workload, however good design also mitigates the workload requirements imposed by the external environment (e.g. ATC and the weather) and Air Traffic procedures. For a single crew aircraft simplicity of operation will be required. Not only will this reduce workload it will also decrease the opportunity for error (and potentially reduce training costs). Having two pilots allows tasks either to be performed in parallel or more complex tasks to be divided between two people. The second pilot helps to distribute workload and is one means of reducing error by acting as an error checking mechanism (e.g. in the execution of checklists). However, there is a workload cost associated with the utilisation of two pilots: it takes workload to work as a team. The requirement to coordinate pilots, cooperate and communicate has workload associated with it. Doubling the number of crew does not halve the workload on each pilot<sup>18</sup>. Furthermore, poor CRM (Crew Resource Management) has been implicated as a factor underlying many accidents. Between 2002-2011 the fifth most frequently cited causal factor for fatal accidents was ‘Flight Crew Use of automation or tools – Failure in CRM (crosscheck/co-ordinate)’. This was implicated in 21% of all fatal accidents<sup>19</sup>. This would imply that both the design of automation and its use can both be improved. However, it also needs to be noted that it is almost impossible to determine the number of times that the second pilot has trapped an error made by the other pilot and averted an accident.

Situation Awareness, be it associated with system management of the flight situation, is a product of good interface design. The development of a single pilot commercial aircraft will primarily be driven by human factors requirements. As a result of the re-analysis of the pilot’s tasks that will be required to specify the flight deck equipment it will be possible to take a fundamentally new approach. New technologies are now becoming available (such as lightweight eye visors; 3D displays; 3D sound; voice command technology; haptic control interfaces) that can support the pilot in new ways, making interacting with the aircraft systems much more natural. Automation/autonomy must be developed to be more transparent in its operation (often characterised as being a better ‘team player’ – not the ‘strong and silent type’) and be more error tolerant, cross checking the pilot where appropriate. The key here is to use the potential benefits of the technology appropriately, not just in individually but in combination, taking a truly pilot-centric approach.

## OPERATIONAL AND ORGANISATIONAL CONSIDERATIONS

In addition to the technological, economic, regulatory and the societal acceptance of the single pilot concept there is one further major issue to address: the organisational aspects of the operation of such an aircraft in airline service.

Removing one of the pilots has ramifications across a wide range of organisational areas. Taking a human-system integration approach, such redistribution of tasks raises substantial issues in areas such as manpower, personnel selection and training. For example, a key manpower question is how many people will be required on the ground to support the pilots in the air (in either aircraft configuration)?

A number of personnel selection issues arise. In the current system, pilots initially train and qualify as co-pilots. They become eligible for selection and training as captains only after they are deemed to have gained sufficient experience in the co-pilot role. As the co-pilot role ceases to exist in a single pilot concept, the question arises concerning how single pilots would gain the necessary experience to operate safely as Captain and how they would be trained? All pilots would effectively have to be Captains. An aircraft commander is not just responsible for flying the aircraft but also for making sound safety decisions concerning operations, crew management and passenger situations. The question also arises as to what experience and qualifications would be required for ground-based personnel and whether they need to be recruited from outside the existing airline resource pool?

The impact of new flight deck systems and operating concepts will require a different approach to training, both that of the individual and as a team. A distributed solution would require training facilities (simulators, computer-based training, simulation of operations rooms including the support stations, etc.) for the ground-based personnel as well as pilots, increasing the complexity of training provision. From a social and organisational perspective, the question arises as to what impact will this new type of operation have on existing airline organisational culture (e.g. promotion and seniority)? There may even be a requirement for a change in the knowledge, skills and abilities required away from the traditional skill set (e.g. manual flying) to one that emphasises delegated authority (e.g. supervising and monitoring systems). This represents a significant shift in role from highly-rehearsed skills to knowledge-based reasoning.

Operating a single crew commercial aircraft will require a re-distribution of tasks between the air and ground, and the pilot and machine. As an example, there will be a requirement to simplify the crew briefing. Pilots will still need to review the flight plan, taking into account weather and Notices to Airmen en-route and at the destination/diversions. However, tasks such as calculation of the final fuel load, weight and balance, critical speeds, etc. could be delegated to the ground or the machine. The question then becomes, would a pilot want to do this? In current operations these tasks can take up to an hour for crew of two: halving the number of pilots on the flight deck would have an unacceptable impact on turnarounds and the pilot's available duty time. Once at the aircraft, the pilots must undertake the walkaround, even though an engineer is required to complete any maintenance and sign the log. One option may be to delegate this task to the engineer.

Hence, alternative solutions need to be sought. Although not directly related to the design of a single crew aircraft, issues such as these dictate the viability of the concept, as overall operating costs need to be reduced by using a single pilot rather than simply redistributed across the airline. Such operational and organisational issues need to be resolved in a manner that is safe, cost effective and organisationally acceptable. Dispatchers and cabin managers may need to be prepared take a degree of control of the aircraft. This will need extensive training and they will expect to be paid for the additional responsibility.

### A DESIGN CHALLENGE

The single crew airliner is still probably 20 years away, however with the legislative developments in the USA it is possible that the single pilot cargo aircraft may be closer to becoming a reality. This will invariably pave the way for single crew airline operations and provide the opportunity to develop the technology required.

Whether or not single pilot operations ever enter commercial service, as a design exercise the single pilot aircraft will provide the opportunity for a re-appraisal of the pilot's tasks on the flight deck, taking a truly human-centred approach. It will almost inevitably derive new pilot-support requirements for development by the avionics companies which will be applicable for single and multi-crew aircraft. It will provide a test bed for new approaches to safety, certification and design processes, and help to address options for the safe recovery of an aircraft in the case of pilot incapacitation. And far from decreasing the need for pilots it may actually increase the need. Parimal Kopardekar, Project Manager for the Concepts and Technology Development Project at NASA Ames Research Center, noted that single pilot operations are ‘a polarizing topic<sup>20</sup>. He suggested that if single crew operations could be implemented the cost per passenger, per mile would decrease and as a result ticket prices would concomitantly fall which would result in an increase in demand, potentially requiring more pilots and more aircraft.

### CONCLUSION

- The key drivers for further reductions of flight deck crew in commercial operations will likely come from sources other than technology (costs, demographics, demand and crew availability).
- The move towards more-automated or autonomous cockpits will be an opportunity to further increase aviation safety and support new developments in key areas of cockpit technologies.
- The effort required to enable this must not be underestimated and the temptation to consider in any way the possibility of replacing further crew without a full redesign of the cockpit flight control systems should be avoided.

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## WHO WE ARE

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

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