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Safety behaviours: human factors for pilots 2nd edition

Resource booklet 10 Design and automation

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Since the early years of powered flight, there has been much discussion about how design and automation influence pilot workload and flight safety. The interaction between people and machines has generated ongoing and extensive research.

This booklet considers the good, the bad and the ugly when it comes to aircraft design and automation. It stresses the importance of understanding the strengths and limitations of technology, and training which takes these into account.

Contents

Technology … is a queer thing. It brings you great gifts with one hand, and it stabs you in the back with the other.

Carrie Snow, stand-up comedian

Introduction

There have been significant, and often rapid, advances in technology in aviation since the Wright brothers' historic flight in 1903. Nowhere is this more evident that in the aircraft cockpit—what would the Wright brothers think if they were to step inside the cockpit of an Airbus A380 or Boeing 787 today?

Consider the following words about cockpit design and human limitations, written more than 65 years ago in the first issue of the 'Aviation Safety Digest':

> The development of the modern aeroplane has resulted in a continually increasing complexity of instrumentation and controls. However, one element of the cockpit has remained unchanged—namely the pilot. He has the same basic limitation—his mental and physical reactions are fundamentally the same, and his reaction time is unchanged.
>
> The modern aeroplane has greater speed, with the result that a pilot has less time to make decisions, while at the same time he must be more accurate because of the decreased margin of error. The improved performance and more complex functional systems have resulted in a greatly increased amount of instrumentation. Thus, the pilot is being provided with more information, all of which must be recognised, analysed and correlated.
>
> The number of controls in the cockpit has increased correspondingly, while frequently a more complex system of control manipulation is necessary. Both the increased amount of instrumentation and the greater number of controls tend to increase the time required for the pilot to assess the situation and to act accordingly. Many so-called pilot errors have resulted from design that failed to consider basic human limitations.[1]

Since that time, advances in technology have again significantly transformed the aircraft cockpit and have altered the relationships between the pilot, the aircraft and their environment.[2]

Advances in safety

If we were to ask design engineers about the greatest advances in aviation safety, many would refer to the introduction of technology from the flight simulator in the late 1940s to today's advanced air traffic management systems.

These comments could be followed by, 'it is a shame that humans haven't developed at the same rate'.

By contrast, human factors experts would tend to say that the greatest advancement to aviation safety has been a scientifically based understanding of specific human performance limitations that must be considered when designing new or advanced technology. For example, we have come to realise that humans are notoriously unreliable at monitoring systems. Unfortunately, many automated systems and advanced technologies require us to monitor a system passively rather than actively control it.

Like the engineers, the human factors experts would also be quick to say, 'if only designers would better understand and consider human factors issues when introducing new technology'.

Therein lies the paradox and the central subject of this booklet. Like fire, technology and automation can be great servants, but make poor masters. Technology is not just operated by humans; we also design, build, install, maintain and check it throughout its lifecycle.

Consider the following quote from former National Transport Safety Board member, John Lauber:

Comments from a number of periodicals, papers journals, and other documents show that cockpit automation increases, decreases and redistributes workload. It enhances situational awareness, takes pilots out of the loop, increases head-down time, frees the pilot to scan more often, reduces training requirements, increases training requirements, makes the pilot's job easier, increases fatigue, changes the role of the pilot, has not changed *the role, makes things less expensive, more expensive, is highly reliable, minimises human error, leads to error, changes the nature of human error, tunes out small errors, increases the likelihood of gross errors, is desired by pilots, is not trusted by pilots, leads to boredom, frees pilots from the mundane, and finally increases air safety and has an adverse effect on safety!*[3]

This booklet focuses on the pros and cons of increasing complexity and use of automation in the cockpit, as well as the introduction of the pilot's checklist as an effective tool to manage this complexity.

The change from an active system controller to an increasingly passive systems monitor presents human performance challenges for pilots, such as 'automation surprise'. This booklet also describes how these issues are being addressed through training initiatives, enabling pilots to operate modern glass cockpit general aviation aircraft more safely and efficiently.

An increasingly automated world

Automation is the use of machines and technology to operate or control a process or system without continuous input from an operator, reducing human intervention to a minimum.

Increasingly these days we see or interact with automated systems: a machine makes our morning coffee; our fruit or cereal is automatically picked, sorted and bagged by machines; our morning 'newspaper' is delivered on a tablet computer; our floors are cleaned by a robot; we have smart phones and TVs; and groceries can be ordered online automatically by a smart refrigerator.

The list of devices (and possibilities) is almost endless—for example, the Boeing 777 was designed entirely on a computer-aided 3D design application known as *CATIA*.

Consider how fast technology has developed. Gadgets we thought a few years ago were science fiction are now a reality. Think back to the greatest predictors of modern day 21st century living—the creators of the original *Star Trek* TV series! The show first aired in September 1966 and offered a fascinating look at what space exploration might look like in the future. A surprising number of before-their-time technological gadgets from the show are now in widespread use. The most obvious influence for designers was the flip-phone communicators used by the crew of the *Enterprise*, which inspired the mobile phone.

Other familiar gadgets include tablet computers, voice interface computers, Bluetooth headsets, portable memory (from floppy disks to USB sticks), automatic doors, big screen displays, and teleconferencing (today's *WhatsApp* and *Skype*).

Figure 1 The digital world, and especially Asia-Pacific, is experiencing spectacular growth, according to a report published in early 2018

JAN 2018 Digital around the world

TOTAL POPULATION	INTERNET USERS	ACTIVE SOCIAL MEDIA USERS	UNIQUE MOBILE USERS	ACTIVE MOBILE MEDIA USERS
7.593 BILLION	**4.021** BILLION	**3.196** BILLION	**5.135** BILLION	**2.958** BILLION
URBANISATION 55%	PENETRATION 53%	PENETRATION 42%	PENETRATION 68%	PENETRATION 39%

JAN 2018 Digital in Asia-Pacific

TOTAL POPULATION	INTERNET USERS	ACTIVE SOCIAL MEDIA USERS	UNIQUE MOBILE USERS	ACTIVE MOBILE MEDIA USERS
4.214 BILLION	**2.007** BILLION	**1.779** BILLION	**4.318** BILLION	**1.713** BILLION
URBANISATION 48%	PENETRATION 48%	PENETRATION 42%	PENETRATION 102%	PENETRATION 41%

A few technologies have not yet been realised, such as the 'beam me up' transporter, able to dematerialise and rematerialise people. Perhaps this is a good thing, because it would most likely spell the end of air transport. Why fly when you can dematerialise?

The invention and development of technology in personal, business and social application, has changed our lives both for the better and the worse. Some positive changes include:

Education: online schools and universities, as well as ease of access to virtual libraries, have allowed people from remote locations or disadvantaged communities to get an education—as long as they have access to a computer and the internet.

The age of 'now' communication: in the past a letter could take weeks to get to a far-flung destination. Today we have mobile, internet, computer and social media, video conferencing tools and mobile apps to communicate instantly with anyone around the world. And if there is an aviation accident or incident, the immediacy of social media means it can become 'instant' news.

Technology has brought some negatives too, such as:

Addiction: many people are addicted to the internet or can't stop themselves habitually scrolling through their phone. This does not encourage creativity or develop social skills and some experts believe it is having a negative impact on brain development.

Health and fitness: sitting down next to a computer all day long has created a largely sedentary society.

Critical thinking skills: Why think when you can use a search engine? Everyone wants to read the easy explanation, risking the development of critical thinking skills.

Dependence: when the technology doesn't work we often can't fix the problem and need to function without it. Compare the difficultly of repairing a fault in a modern electric car with one in an HQ Holden!

Evolution of cockpit technology

The most significant advances in cockpit technology have only occurred in the past few decades. From the beginnings of powered flight up to the 1970s and 1980s, traditional analogue flight instruments and displays were commonplace. However, in those early years, there was little standardisation in their layout or presentation to make them more usable and functional.

While pilots were trained initially on the principles of avionics and systems management, it was assumed that they would be able to apply their knowledge to all aircraft because all flight instruments looked and worked essentially in the same way. As a result, transition to a different aircraft type involved only cursory instruction on the new avionics or systems. The focus of flight training was largely on traditional 'stick and rudder skills' and learning the handling characteristics of each aircraft type.

With advances in technology, and as aircraft became more complex, so too did the flight instruments and cockpit systems needed to manage them. The two world wars gave rise to rapid advancements in aircraft design and performance.

However, as mentioned in the introductory booklet, the realisation that more pilots were lost from training accidents and 'pilot performance', rather than enemy action, was the catalyst for change. Designers began to focus on standardisation of flight instruments and complexity of cockpit systems in an effort to reduce accidents attributed to 'pilot error'.

Boeing Model 299 accident

The loss of the prototype Boeing 299 Flying Fortress in 1935 turned the attention of designers to developing checklists and procedures to enable pilots to manage more complex systems safely.

The Boeing Model 299 was an advanced design proposed for a new bomber for the US Army Air Corps (USAAC). Compared with its twin-engine competitors, it was a very large and complex four-engine aircraft, with additional instruments and controls placing greater demands on the pilots' attention.

From the initial evaluation, its performance was vastly superior to the competition. Boeing seemed certain to earn a lucrative United States Army Air Corps (USAAC) contract, until tragedy struck.

Figure 2 Cockpit of the Boeing Model 299

image: National Museum of the U.S. Air Force

On 30 October 1935, the Model 299 underwent its second evaluation flight, flown by Boeing's chief test pilot, Leslie Tower, and USAAC test pilot Major Ployer Peter Hill. Soon after take-off, the aircraft entered a steep climb, then stalled and crashed. The aircraft was destroyed and both pilots were killed, while several others on board received severe injuries. Finding no evidence of mechanical malfunction, the accident investigation team concluded that the cause of the accident was 'pilot error'.

Figure 3 Aftermath of the Boeing 299 crash during its second evaluation flight

image: National Museum of the U.S. Air Force

The error was actually very simple—the crew had forgotten to disengage the 'gust lock' which locked the control surfaces. Because of the size of the aircraft and the design of the control system, it is unlikely that the pilot would have discovered the controls were locked until the aircraft became airborne, by which time it was too late—the aircraft was uncontrollable.

One newspaper article at the time concluded that the Model 299 was just 'too much plane for one man to fly'. This prompted a new consideration of human performance limitations, and the realisation that perhaps modern planes had become too complex to operate safely. They had begun to exceed the capabilities of pilots to remember all the tasks required to fly them safely.

If highly trained test pilots could forget such a basic step as disengaging the control lock, the aircraft would almost certainly exceed the abilities of the average army pilot.

Birth of the checklist

The solution put forward by Boeing was innovative, simple and very effective: the pilot's checklist. Before that, pilots had been expected to learn the aircraft systems and operate them from memory. This was fine when the start sequence was only five to ten items, but when it involved four engines, numerous control system checks and dozens of individual steps, even the test pilots were finding it all too easy to miss a few simple (but vital) steps. Checklists made it easier for pilots to manage more complex cockpit systems, to ensure they did not miss important steps during crucial phases of flight.

As it turned out, the aircraft was *not too much for one man*, but simply *too much for one person's memory*. Checklists would ensure that none of the vital steps required during critical phases of flight was forgotten. All these steps would be listed and performed in order, and the pilots would consult the checklist, rather than rely on memory.

Four checklists were initially developed: for take-off, in-flight, before landing and after landing; and all pilots were taught how to use the checklists as part of their training.

Pilots soon realised that checklists not only improved safety but helped them to work more effectively and efficiently. They reduced workload and increased the margins of safety; and allowed designers to overcome the limitations of human memory. The checklist concept was so successful and so widely accepted it enabled aviation to become more and more complex.

Checklists and procedures are now commonplace in all safety critical industries and were a key to managing complex systems design. Checklists were developed for almost every part of the Apollo mission, with each of the Apollo 11 astronauts logging more than 100 hours of simulator time familiarising themselves with these checklists. In fact, checklists were so integral to the success of the Apollo moon landings that astronaut Michael Collins dubbed them 'the fourth crew member'.

Cockpit design

Early cockpits were rudimentary, with a few levers and controls, a steering wheel that resembled a bicycle wheel, and a few essential flight instruments. As the complexity of aircraft increased, the amount of information required by pilots to operate these aircraft safely also increased. As new systems and displays were added, so was the opportunity for further error, and finding space in already crowded cockpits became an issue.

Figure 4 Example of an early cockpit showing simplicity of design

image: Library of Congress, Prints & Photographs Division, photograph | Harris & Ewing, [reproduction number, LC-DIG-hec-01491]

Figure 5 Example of basic flight instruments. Note the joystick that resembles a baseball bat

image: Jenny cockpit | Eric Gideon

By the mid-1970s, the average commercial airliner had more than 100 cockpit instruments and controls, with additional alerting and warning systems. The primary flight instruments were already crowded with indicators, crossbars and symbols, and the growing number of controls and displays were competing for space and the pilots' attention.

Figure 6 Cockpit of Boeing 747 'Classic' showing complexity of instruments and displays

image: NASA SCA N905A | Ian Abbott

Complexity paradox

The increased number of systems and displays had the opposite effect to that intended by their designers. Despite increasing use of alerting and warning systems, pilots were still making errors and poor decisions.

Designers responded initially by developing even more complex automated systems to design 'pilot errors' out of the system. However, this created further demands on pilots to monitor systems for malfunctions or failures, and thus further opportunities for error.

The design of the cockpit, and increased workload had again begun to exceed pilots' capabilities and limitations. Human factors experts and researchers began working together on cockpit design and reducing pilot workload.

Their efforts were focused on designing improved displays which could combine information from various flight instruments and aircraft systems. At the same time, they looked at ways of improving interaction between pilots and cockpit automation, referred to as the *human-machine interface* (HMI).

Development of the glass cockpit

Advances in microprocessors enabled the development of more sophisticated electronic flight instrument systems (EFIS). Early EFIS displays were simply electronic versions of the traditional six-pack of analogue flight instruments displayed on small TV-like screens called cathode ray tubes (CRTs). These were referred to as 'glass' instruments, giving rise to the term 'glass cockpit'. CRTs were later replaced by larger liquid crystal displays (LCDs), which offered improved efficiency, reliability and legibility.

Figure 7 Traditional light aircraft cockpit with enlarged view of the 'six pack' of flight instruments

image: iStockphoto.com | Kris Hanke

image: iStock.com | Tom Prout

LCD screens enabled the six-pack to be combined in a single *primary flight display* (PFD); while the *navigation display* (ND) combined a moving map display with weather radar and terrain features, radio and navigation information and traffic information.

Additional LCD screens integrated engine indications and systems information, as well as including electronic checklists for systems malfunctions. These displays provided the pilot with better quality information to create a clearer picture, or *mental model*, of the aircraft's status and situation.

Figure 8 Primary flight display (PFD)

image: © Civil Aviation Safety Authority

Figure 9 Navigation display (ND)

image: © Civil Aviation Safety Authority

Glass cockpits were introduced initially into military aircraft in the 1960s. Following extensive research by the US National Aeronautics and Space Administration (NASA), they were introduced into commercial airliners in the mid-1970s. The first glass cockpit aircraft registered in Australia was the Saab 340, in 1985.

This technology has become the norm for many business jets and general aviation aircraft. In 2003, the Cirrus Design Company produced the SR20 and SR22, the first light aircraft equipped with glass cockpits. By 2005, glass cockpits were an option for new models of legacy training aircraft, such as the Piper Cherokee and Cessna 172.

Figure 10 Example of glass cockpit flight displays showing PFD and multi-function display (MFD)

image: © Civil Aviation Safety Authority

Multi-function displays (MFDs) combined the features of the navigation display with engine and systems information, communication and navigation frequencies, and electronic checklists. The MFD is also capable of displaying information on airspace and airports, and includes 'range rings' for fuel endurance, as well as weather information for selected airports. The information and features displayed are selectable and transferable between screens, allowing pilots to select the most appropriate displays for the phase of flight.

Figure 11 MFD showing moving map and weather display

image: © Avidyne Corporation

Implementing automation

Within aviation, automation refers specifically to *any system of automated guidance and/or control that is capable of altering (either directly or indirectly) the aircraft's flight path or energy state*. We tend to use the term as a general reference to the automated systems found in the aircraft cockpit, or flight deck.

A century of progress

Cockpit automation is not new. In 1912, less than 10 years after the Wright Brothers' first flight, the Sperry Corporation developed the first autopilot. It allowed aircraft to fly straight and level on a set heading, without intervention by the pilot, thus reducing workload. Two years later, Sperry developed the first three-axis autopilot, the first example of a flight path management system. The race to automate aircraft cockpits was off to a flying start.

Long before the silicon chip and digital displays, analogue examples of autopilots, flight directors, yaw dampers and other mechanical devices played a significant role in automating flight. Autopilots have since come a long way; they are now capable of completing an entire flight with minimal physical input from the pilot, including automatic take-off, landing, and almost everything in between.

Monitoring performance

Throughout the 1970 and 1980s, the overriding philosophy of designers was that cockpit automation should *control* systems, while pilots should *monitor* their performance. It was recognised that the continuous control of systems was often beyond normal human performance capabilities. Moreover, it was not the most efficient use of humans' abilities to analyse and manage complex situations.

However, investigations into accidents and incidents continued to confirm what researchers and designers already knew—that humans are not reliable monitors, especially when monitoring highly reliable systems.

Despite decades of research into human performance and limitations, designers continued to make the seemingly contradictory assumption that while pilots were not very good monitors, this is what they should continue to do. The designers just added more technology and automation to monitor the performance of the pilots and remind or alert them to take necessary action.

Design philosophies

Two distinct approaches to the design of automation began to emerge; these are referred to as the *technology-centred* and *human-centred* approaches.

Technology-centred automation seeks to overcome the limitations of human performance by replacing human functioning with machine functioning. The overriding design philosophy is to use automation wherever possible to reduce pilot workload and eliminate errors. Designers seek to exploit the accuracy and efficiency of automation to achieve economies such as fuel efficiency, passenger comfort and reduced training costs.

By contrast, human-centred automation seeks to enhance the capabilities of, and compensate for, the limitations of human performance. The philosophy is not to replace human functioning, but rather to enhance human effectiveness by optimising workload and supporting the pilot in managing complex systems and making effective and timely decisions.

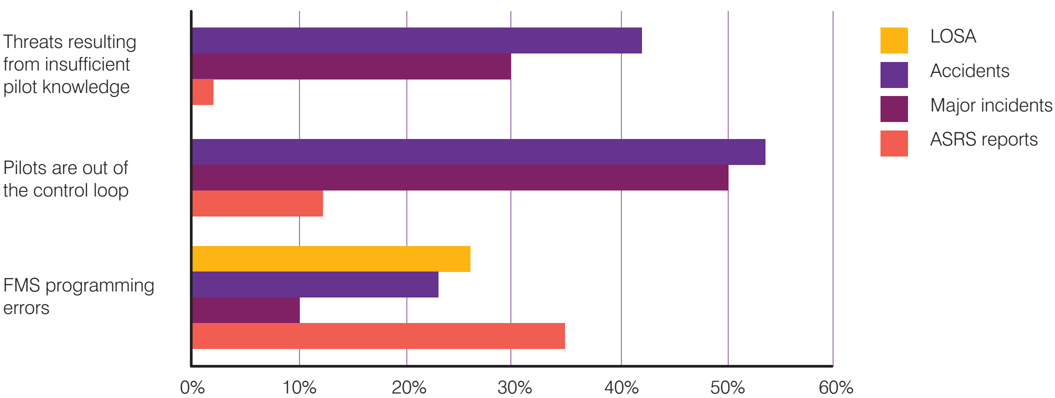
Keeping pilots in the loop

There are concerns that technology-centred automation has taken pilots 'out of the loop', to the extent that they may not be able to adequately perform their monitoring and supervisory roles. Many of the human performance issues that have been identified for many decades, such as *error introduction* and *error recognition*, remain unresolved. Designers have now realised that the goal of eliminating human error from the cockpit is unrealistic and unachievable.

The maxim 'as long as we are human we will continue to make mistakes' has held true through the history of flight. That is, while the environment in which pilots operate has changed considerably in recent decades, the human condition has not, and we will continue to make mistakes, no matter how well intended our efforts.

Systems design over the past 10-15 years has been more human-centred than in the past, with an emphasis on training pilots to *recognise and manage errors*, rather than making futile attempts to eliminate them.

Figure 12 Examples of pilot-related insights from automation data



Proportion of source data citing issue

LOSA = line operations safety audit; FMS = flight management system; ASRS = Aviation Safety Reporting System
Notes: The working group's analysis of events used database subsets that fell within the scope and time frames specified in its final report. The data shown does not represent the frequency of occurence for all accidents, major incidents, ASRS reports or LOSA reports from these time frames.
Source: Flight Deck Automation Working Group

image: © Twin Otter instrument panel | Civil Aviation Safety Authority

Longer flights, fewer crew

Before the invention of the autopilot, flying an aircraft required the continuous attention and intervention of a pilot. As aircraft design and flight instruments became more complex, aircraft range and performance increased, allowing flights of many hours duration at higher altitudes. As a result, human performance issues such as fatigue, attentional deficiencies and vigilance became increasingly important.

In 1985, Earl L. Wiener,[5] a leading expert in human factors and automation in aviation, identified several significant advantages of cockpit automation:

- safety
- economy, reliability and maintenance
- workload reduction and certification of two-pilot commercial transport aircraft
- more precise flight manoeuvres and navigation
- display flexibility
- economy of cockpit space
- catering for the special requirements of military missions.

While Wiener's research focused primarily on commercial airliners, most of these principles apply equally to charter and GA. Advances in automation and design have allowed the certification of some high-performance turbo-props and business jets from two-pilot to single-pilot operations. These include the Beechcraft Kingair, Pilatus PC-12, Hawker Premier, Embraer Phenom 300, and several Cessna Citation models.

New errors

As digital technology advanced, there was a push by designers to put it to good use in aircraft cockpits. The intention was to address pilot workload issues and automate human error out of the system by replacing human functioning with machine functioning. However, there were two flaws in this reasoning.

First, the devices themselves had to be designed, operated and maintained by the same people whose limitations they were designed to avoid. The result was that human error was not eliminated, but relocated.

Second, the devices themselves, and their interactions with pilots, had the potential for generating errors which could also lead to incidents and accidents.

Figure 13 Cockpit of a Pilatus PC-12 on a single pilot charter flight

image: © Pilatus Aircraft Ltd

On 28 November 1979, an Air New Zealand DC-10, operating a scenic flight over to the Antarctic, crashed into the slopes of Mt Erebus. The initial investigation found the cause of the accident was pilot error. However, a later Royal Commission of Inquiry determined the accident was caused, in part, by a correction to the flight plan coordinates, made without informing the flight crew, which resulted in the aircraft flying directly towards Mt Erebus, rather than down McMurdo Sound as the crew had been led to believe.[6]

In the midst of Cold War tensions on 1 September 1983, Korean Airlines flight 007 en route from Alaska to Seoul, was shot down by a Soviet fighter in the Sea of Japan after it was assumed to be a spy plane. The aircraft had strayed hundreds of miles off course because its autopilot was operating in the wrong mode and continued to fly the aircraft on an incorrect heading. The disaster led to a decision by then US President Ronald Reagan to make the GPS system available to civilian aircraft. The autopilot interface on some aircraft was changed to make the mode in which they were operating more obvious.[7]

The pilot's role

Much of the debate about the advancement of technology in aircraft cockpits has focused on the changing nature of the pilot's role from actively controlling the aircraft, to monitoring the automated systems, (*the pilot monitoring the machine*) and the corresponding safety implications. The introduction of advanced cockpit monitoring and alerting systems have played a role in overcoming pilot performance issues (*the machine monitoring the pilot*) and enhancing flight safety.

Devices in the cockpit automate or *eliminate* pilot actions, including many autopilot and auto-throttle functions; other devices remind the pilot to take action, such as the altitude alerting system to warn of deviations; while other devices *deman*d the pilot take action, such as ground proximity warning system (GPWS), terrain awareness warning system (TAWS) alerts and warnings, and traffic collision avoidance systems (TCAS) resolution advisories.

Some automated systems are designed to *take action* should the pilot fail to heed warnings, such as the stick pusher system which automatically pushes the control column forward, should the pilot fail to make a corrective input as the aircraft approaches an aerodynamic stall. Other systems *prevent pilot actions* by limiting in-flight manoeuvring and g-loads to avoid potentially over-stressing the airframe or flight controls.

While there is no doubt that these safety features have had a positive effect and saved countless lives, they have also introduced further opportunities for error or confusion, and rely on pilots taking appropriate actions to respond to the warnings.

TCAS were designed to reduce the occurrence of mid-air collisions and near-misses by issuing avoidance instructions to conflicting aircraft, known as resolution advisories. Similarly, TAWS and GPWS were designed to warn pilots of the proximity of potentially hazardous terrain. However, to operate effectively, pilots must respond appropriately to the system warnings.

- In 2002, confusion by pilots as to which instructions they should follow when faced with conflicting instructions from air traffic control (ATC) and from TCAS, led to a mid-air collision between a Tupolev Tu-154 passenger aircraft and a Boeing 757 cargo aircraft near Überlingen, killing 71 people.[8]
- In 2015, the pilots of a Learjet deliberately flew too low and disobeyed the TAWS. One of the pilots said ‘ah, shut up’, before disabling the TAWS moments before the aircraft crashed on approach, killing all nine on board.[9]

Figure 14 TCAS on navigation display

image: TCAS integrated in Navigation Display (ND) | JetRequest.com

Figure 15 Flight management system (FMS)

image: © Ondrejschaumann | Dreamstime.com

Economy, reliability and maintenance

Advancements in satellite navigation and the introduction of integrated flight management systems (FMS) have allowed aircraft to fly more accurate and efficient flight paths, reducing flight times and fuel burn, as well as crew and maintenance costs. If we consider that the fuel bill for the world’s commercial airlines was estimated to be $130 billion in 2017, a one per cent saving in fuel burn would equate to an annual saving of $1.3 billion.[10]

Increasingly, the benefits of advanced technology are filtering down into charter and GA aircraft. Advanced autopilot and auto-throttle systems, together with GPS and FMS, allow GA aircraft to be flown more accurately and efficiently, and with considerable cost savings. The introduction of LCD and integrated displays has made advanced technology aircraft more cost effective and reliable to operate and maintain.

Workload reduction and crew complement

A central theme and motivation for increasing cockpit automation has been to reduce pilot workload. Wiener suggests the three key objectives of cockpit automation are to:

- reduce pilots’ physical and cognitive workload so that they have more time and mental capacity to manage the flight more effectively, and to perform optimally in emergency situations
- allow pilots to spend less time ‘head down’ in the cockpit, and more time maintaining an effective lookout for traffic and other threats, such as hazardous weather and terrain, particularly in the terminal area
- lessen the workload to allow a reduction in minimum crew complement.

However, pilots and manufacturers may sometimes disagree about benefits of automation. Pilots often complain that certain systems increase workload rather than reduce it. But automation has assisted pilots to manage workload to the point where manufacturers and regulators have allowed a reduction in the minimum crew complement for more advanced aircraft cockpits, from airlines to GA.

Figure 16 Compare the cockpits below: (a) 2-Pilot and (b) Single-Pilot

(a) image: Cessna Citation 560XL cockpit | CC BY-SA 3.0

(b) image: Cessna Citation Mustang instrument panel | jetav.com

More precise flying

As commercial traffic increased, and available airspace became more congested, more precise navigation systems were required to improve accuracy and reduce separation minimums without compromising safety. More flexible air routes and precise approaches were also needed. Such precise navigation was beyond our human capabilities and those of current autopilots and navigation aids.

Satellite-based systems, such as global positioning system (GPS), offer precision and flexibility, and in suitably equipped aircraft, can allow curved final approach paths to avoid terrain and airspace constraints. However, these systems place demands on pilots to program and monitor such approaches accurately, and add further workload: more automation and warning systems for the pilot to monitor and assess.

GPS technology was rapidly adopted for use in general aviation as it became more available and affordable, often ahead of regulatory and training considerations. This reversed the usual trend of technology being 'tried and tested' in commercial airliners before filtering down.

Research by Nendick and St. George[11] found that the introduction of GPS changed the navigation strategies and skill levels of GA pilots, and affected their decision making and judgment. GA pilots quickly developed overconfidence in GPS, to the detriment of their basic navigation skills, often failing to consider a back-up plan when GPS was not available.

The same applies to tools such as electronic flight bags.

Display flexibility

Glass cockpit displays are software driven and allow the display of information in formats not possible previously. Symbols, colours, text, 2D- and 3D-displays, and enhanced graphics such as head-up guidance systems and synthetic flight displays are all possible.

Electronic crew alerting systems, including visual and auditory alerts and warnings, combined with electronic checklists, can direct the pilots' attention to critical system changes and offer recommended remedial actions.

But with greater flexibility comes the potential for greater problems.

The automation paradox

Wiener suggests that, as a generalisation, automation tunes out the small errors and creates opportunities for large ones.

Following the launch of a Space Shuttle flight in 1983, NASA admitted to what was probably the largest navigational error in history. When the coordinates were entered for the point at which the fuel tank would fall into the ocean after jettison, *north* rather than *south* latitude was entered, resulting in an error of 114 degrees. The incorrect latitude in the northern hemisphere resulted in projected impact point of the fuel tank in Russian airspace, near the Kamchatka Peninsula.

While designers have often focused on reducing the *physical* workload of the pilot, they have not adequately considered the effect this may have on increasing the pilot's *cognitive* or mental workload.

Pilots have expressed concern about the mental workload required to operate and monitor increasingly complex automated systems. These systems require more cognitive processing and a greater understanding of their design and functions.

Glass cockpit displays have many options and can become cluttered with symbols, text, warnings, and a dazzling array of colours. There is a risk of incorrect data entry or mode selection, and it can be difficult for the pilot to access information quickly, particularly if it is buried within menus. There is real potential for pilots to deselect or miss pertinent information, and risk losing, or degrading their situational awareness.

Promises and problems

Pilots often joke that the most common sayings in glass-cockpit aircraft are 'what happened then?', 'why did it do that?', and 'what is it doing now?' However, there is some truth to this.

Research and accident investigations show that pilots can become confused about autopilot modes, rely too much on automation, and hesitate to intervene when things start to go wrong. We often attempt to program our way out of trouble, rather than disconnect the automation and fly the aircraft manually.[12]

Wiener and Curry[13] refer to the 'promises and problems' of automation. The unintended consequences are often the result of inadequate consideration of human factors principles at the design phase, such as:

- the potential for data-entry errors
- mode awareness/mode confusion
- over-reliance on automation
- automation-induced complacency
- startle and surprise.

Small errors, big consequences

The need for continual programming of the flight management (FMS) and other cockpit systems creates increased opportunity for data entry errors. Importantly, the size of the actual input error does not relate directly to its consequence.

A minor error can have major and devastating consequences. Consequently, to capture and correct data entry errors, it is essential to have robust cross-checking procedures, and ensure everyone follows them.

On 20 March 2009, one mistyped, undetected and uncorrected digit on the flight deck of Emirates Flight EK407, an Airbus A340 departing Melbourne, almost led to what could have been the worst crash in the history of Australian aviation.

Using an electronic flight bag (EFB), the first officer calculated the required take-off speed, but instead of entering the intended weight of **3**62.9 tonnes the first officer inadvertently entered **2**62.9 tonnes. The design of a keyboard with the '2' and the '3' adjacent to each other, the preoccupation with a departure clearance, cockpit busyness and a slightly misaligned keystroke produced a lift-off speed 100 tonnes out.

None of the four pilots noted the aircraft's acceleration was dangerously sluggish and that the 3.5 km of runway was being consumed. Much further along the runway than normal, and at the spuriously calculated lift-off speed, the captain called 'rotate'. The first officer duly initiated a nose-up command to the sidestick, but nothing happened. With the aircraft 100 tonnes heavier than calculated, there simply wasn't enough lift.

The A340 overran the end of the runway into the grass and dirt, its tail carving a near continuous rut before slowly inching its way into the air—so slowly in fact that it struck a ground-based strobe light (about 30 cm high), the localiser near-field monitor antenna (about 60 cm high) and finally the main localiser array (about 3 m high).[14]

Mode awareness errors and confusion

The flexibility which glass cockpit technology offers comes at a price. The more choices, the greater the opportunity for errors and confusion, such as in which mode the autopilot is (or should be) operating.

We must have some awareness of the operation of each mode, and the pros and cons for each. When designers offer more choices, but limited guidance as to how each should be used, new and more complicated errors can result.

Over-reliance

As the level of automation increases, by definition, the need for manual control of certain processes reduces. Modern autopilots can fly the aircraft more accurately and efficiently than human pilots. There is a risk that manual flying skills will degrade to the point that we are no longer feel confident or able to fly manually in the event of a system malfunction.

Over-reliance on automation is related to several factors, including the level of experience required for a task, and the pilot's lack of confidence in their ability to perform the task manually. When things go wrong, it is often the pilot who must intervene to recover the situation.

We may be hesitant to take over manual control if we are not confident in our ability to do so, or feel we are no longer proficient in such tasks. There is a similar concern about the risks of over-reliance on automation in areas from self-driving vehicles to spell-checkers.

On 1 June 2009, an Air France Airbus A330 en route from Rio de Janeiro to Paris crashed into the Atlantic Ocean, killing all 228 on board. The aircraft had entered an aerodynamic stall after the autopilot disengaged because of inconsistencies between airspeed measurements, likely caused by ice crystals in the aircraft's pitot tubes.

The final report by the French investigators concluded that the crew had failed to follow appropriate procedures for loss of airspeed information. Without reliable information about the aircraft's angle of attack, the crew had made inappropriate control inputs.

The pilot flying had failed to recognise that the aircraft was stalled, despite a stall warning. *Vanity Fair* writer and former airline pilot, William Langewiesche, wrote that once the angle of attack became extreme, the system rejected the data as invalid and stopped the warning, with the perverse result that each time the pilot lowered the nose, the warning started again.[15]

Another incident was the crash of Indonesia Air Asia flight QZ8501, an Airbus A320, on 28 December 2014 with the loss of 162 lives. This was also found to be the result of an aerodynamic stall resulting from loss of control following attempts to fix a recurring problem with the rudder travel limiter units.[16]

Automation-induced complacency

As autopilots and automated systems become more reliable, we tend to place greater trust in them and become less vigilant when monitoring their functionality and performance. This has led to what researchers refer to as *automation-induced complacency*, and it has been identified as a factor in many aircraft accidents, particularly in those involving aircraft with sophisticated glass cockpits.

It is important to note that complacency is different from boredom, low workload or simply lack of attention. Complacency relates to trust, confidence and reliance on automation to 'do the right thing', whereas *automation-induced* complacency often leads to delays in detecting changes in autopilot performance and system failures. We are hesitant to intervene at the first signs of trouble as we have a high level of trust in the system to correct itself, and often leave it until it is too late to intervene.

Startle and surprise

Startle and *surprise* are often used interchangeably to describe unexpected situations in the cockpit and how we respond to them. While there are similarities between startle and surprise, there are also important differences and implications for pilot behaviour and flight safety.

Startle refers to our immediate reflex response to sudden, unexpected events, and is related to our 'fight-or-flight' reaction.[17] An example is a loud bang, a bird strike on the windshield, or a sudden decompression. Our immediate reactions include an increase in heart rate and a flinch of the muscles to prepare to protect ourselves against a perceived threat. Startle can involve an element of fear or concern for our wellbeing, as well as other physiological and emotional responses.

Research by Rivera and others[18] has found that startle disrupts our cognitive processing (the ability to think clearly) and can have a negative impact on our decision-making and problem-solving abilities. That is, it can take time to recover our senses just at a time when we are most likely to have to react quickly and decisively to recover an abnormal situation; when we must determine what has happened and decide on an appropriate course of action.

Although we may experience startle and surprise together, surprise can occur without a startle event. *Surprise* can be described as a combination of physiological, cognitive and behavioural responses. Similar to startle, reactions include increased heart rate and loss of cognitive processing. However, surprise also involves an inability to comprehend a situation; there is a 'mismatch' between our expectation of a situation, and our perception of what is occurring.

Safety reports have identified several factors that can contribute to surprises, including aircraft state (automation, system alerts), environmental conditions (turbulence, low visibility), instructions from air traffic control (ATC) or other aircraft, and the sudden appearance of other traffic. However, events do not need to be unusual or novel to be a surprise; in fact, most reports involved a routine flight occurrence or procedure that turned into an unexpected event.

Consider the following examples, in which you are visual on final in good weather to a familiar airport, and the runway ahead of you is clear.

- You are expecting a landing clearance from ATC, but instead you are instructed to go-around and conduct a missed approach. This instruction from ATC would be a *surprise* as it is unexpected, and you cannot initially understand the reason for the instruction.
- This time, instead of the go-round instruction from ATC, you suddenly see another aircraft turning final immediately in front of you. This would be considered a *startle* event.

Startle and surprise events have become a significant focus for training in recent years. As we better understand the factors that lead to these events, and their implications for pilot behaviour, we can better prepare pilots to have the situational awareness to manage and recover from them. Resource booklet 6 discusses situational awareness in more detail.

The introduction of random, unexpected events during simulator training, such as a rejected take-off or go-around, to avoid predictability and anticipation of events, helps pilots develop better coping mechanisms to manage these situations.

Lessons from self-drive cars

Just as we have experienced in aviation, the race to automate self-drive vehicles has brought about both promises and problems.

In May 2016, the driver of a Tesla Model S was killed while operating the car in 'autopilot' mode. The accident raised questions about the safety of systems that can perform driving tasks for long periods with little or no human intervention. The Tesla collided with a semi-trailer that had crossed the highway in front of the vehicle. The driver and the Tesla's automated driving control system failed to detect the vehicle.

Investigation by the NTSB[19] found that the Tesla's autopilot operated within its limitations, but the driver was using it in a way for which it was not designed. The probable cause of the accident, cited by the NTSB, reads (in part):

Contributing to the car driver's overreliance on the vehicle automation was its operational design, which permitted his prolonged disengagement from the driving task and his use of automation in ways inconsistent with guidance and warnings from the manufacturer.

The driver engaged with the steering wheel only seven times for a total of 25 seconds in the 40 minutes prior to the accident. The autopilot sensed that the driver was not engaging with the steering wheel for long periods and issued visual and auditory warnings each time. The vehicle is designed to issue three such warnings before it automatically slows to a stop with the hazard lights on. However, on each occasion, the driver engaged with the steering wheel to cancel the warning and reset the system.

Dr Ensar Becic of the NTSB concluded that 'the pattern of use of the autopilot, including the lack of steering wheel interaction and lack of response prior to the crash, shows over-reliance on the automation'. In response, a Tesla spokesperson stated 'we will evaluate their recommendations as we continue to be extremely clear with our current and potential customers that autopilot is not a fully self-driving technology and drivers need to remain attentive at all times'.

The NTSB is also investigating another fatal crash, on 23 March 2018, in which a Tesla car crashed into a freeway divider near Mountain View, California, killing the driver. Tesla blamed the driver, claiming that he was aware the autopilot was not reliable at that location.[20]

Technologically advanced aircraft in general aviation*

So how do the issues of design and automation affect us as GA and charter pilots? What are the significant issues that we may face with increasing technology in GA aircraft?

EFIS equipped aircraft have been entering the general aviation fleet in increasing numbers since the early 2000s. The term 'technologically advanced aircraft' refers to aircraft equipped with at least the following:

- electronic display of primary flight instruments
- a moving map display
- IFR-approved GPS navigation
- an autopilot capable of flight path management.

* As the term technologically advanced aircraft shares initials with the former Australian domestic carrier Trans Australia Airlines and the term 'glass cockpit' is used widely to refer to technologically advanced aircraft this booklet will use the term 'glass cockpit' rather than 'TAA'.

Nearly all new production GA aircraft go beyond the minimum instrumentation listed above, with enough electronic displays to resemble a modern glass cockpit airliner.

The Aircraft Owners and Pilots Association (AOPA) has adopted a working definition of glass cockpit GA aircraft as having a primary flight display (PFD) and a multi-function display (MFD). A recent study by the US National Transportation Safety Board[21] found that more than 90 per cent of new production GA aircraft are being delivered with glass cockpits.

As these aircraft continue to arrive in Australia in greater numbers, it is increasingly likely that most GA pilots will transition to glass cockpits at some point. Conversely, those who have trained on glass cockpit aircraft may need to adjust to analogue instruments when flying older GA aircraft.

This raises several safety implications and considerations for training. Will GA benefit from the lessons learnt by the airline industry in recent decades, or is history destined to repeat itself?

Accident history: is glass safer?

The AOPA Air Safety Foundation (ASF) analysed GA accidents in the US from 2003 to 2006 involving glass cockpit aircraft, the time when they were first introduced into GA. It compared these with the overall GA accident rate.[22]

During this period, GA glass cockpit aircraft accounted for:

- 57 of the 3722 total accidents
- 18 of the 792 fatal accidents
- 2.8 per cent of the total GA fleet
- 1.5 per cent of all GA accidents and
- 2.3 per cent of fatal accidents.

For both total and fatal accidents, glass cockpit aircraft had fewer than half as many take-off and climb accidents as the overall GA fleet.

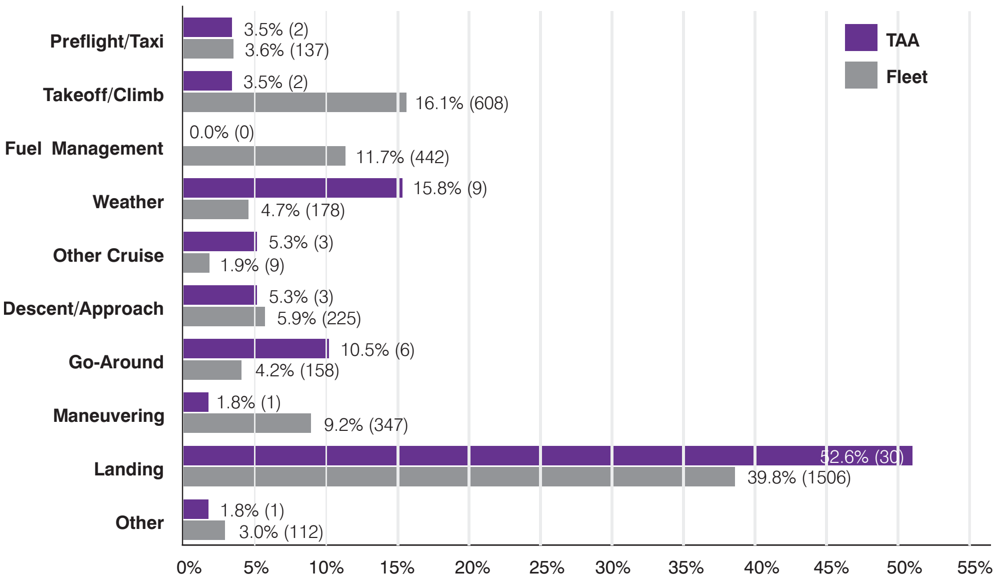
The ASF suggests a contributing factor for this improvement may be that glass cockpit aircraft can display critical take-off speeds (or V speeds) directly on the airspeed indicator, giving the pilot better awareness of the current speed versus the target take-off airspeed.

However, the study also found that glass cockpit aircraft had a higher percentage of landing (52.6 per cent compared with 39.8 per cent) and go-around (10.5 per cent vs. 4.2 per cent) accidents compared with the overall GA fleet, although there were no fatal landing accidents for the glass cockpit fleet.

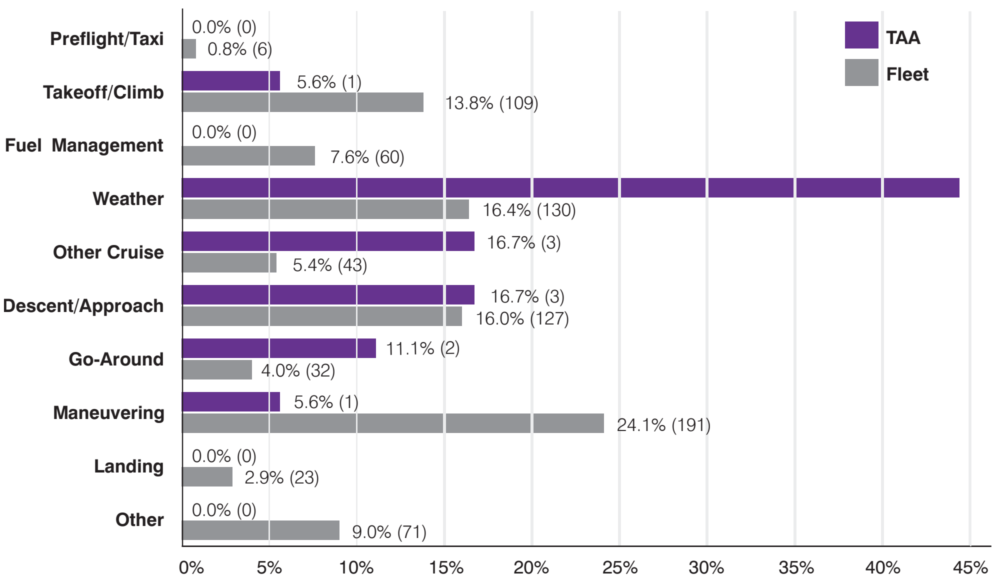
The ASF suggests that the reason may be the higher performance and more difficult handling characteristics of glass cockpit aircraft during the approach and landing phase, and for the go-around.

Figure 17 Comparison of accident rates for TAA (glass cockpit) versus GA fleet; (a) total and (b) fatal accidents

Pilot related accident categories, TAA vs fleet (a) total



Pilot related accident categories, TAA vs fleet (b) fatal



FUEL

Significantly, during the study period, glass cockpit aircraft recorded no fatal accidents related to fuel management—an important victory over one of the leading causes of fatal GA accidents. This may be directly attributable to the added design features of glass cockpits, which include a 'range ring' on the map display to indicate the range of the aircraft, calculated at the current fuel flow and groundspeed, while also displaying airports nearby.

In Australia, it is now mandatory for pilots who expect to be landing with less than their fixed fuel reserve to broadcast 'Mayday Fuel', to alert air traffic control and other traffic that they require priority to land as quickly as possible.

MANOEUVRING

The US study also found that manoeuvring accidents—another leading cause of fatal accidents in GA overall—were also greatly reduced in glass cockpit aircraft. The study found that while 9.2 per cent of all GA accidents occurred during manoeuvring flight, these accidents accounted for 24.1 per cent of all fatal accidents.

By comparison, the figures for glass cockpit aircraft were 1.8 per cent and 5.6 per cent respectively. While the reasons for the improvement are unclear, the ASF speculates that, as a higher percentage of the glass cockpit aircraft fleet was used for private flying, they likely spent more time en route rather than manoeuvring, such as during flight training.

This appears to have been the case in the following ASF case study:[23]

A private pilot was conducting an IFR flight between Winston-Salem, North Carolina, and Fredricksburg, Virginia. The pilot attempted a night GPS instrument approach but executed a missed approach. He subsequently requested and flew an ILS approach to the Stafford, Virginia, airport. Radar and transponder returns confirmed the aeroplane flew the localiser course down to about 200 feet above ground level (AGL).

Weather at the time of the accident included calm winds, 2000 metres visibility, light drizzle, and an overcast ceiling of 500 feet. The aeroplane's wreckage was located in a wooded area, about 100 metres left of the runway and three quarters of the way down its 1500-metre length. Tree cuts were consistent with the aircraft having been in a 30-degree left turn. The missed approach procedure was to climb to 600 feet above mean sea level (AMSL) (about 400 feet AGL), then make a climbing left turn to 2000 feet, direct to a VOR, and enter the hold. There was no evidence of mechanical malfunction.

The ASF commented:

The evidence in this case is consistent with the pilot failing to establish a positive climb while following the missed approach procedure. The Columbia 400 is a new generation, high-performance [glass cockpit] aircraft. When executing a missed approach, the application of power and subsequent need to trim for a climb could lead the pilot into a difficult situation if priorities are not established correctly. The old maxim of 'aviate, navigate, communicate' is as valid for the [glass cockpit aircraft] as it is in conventional aircraft. Training to maintain proficiency in challenging manoeuvres such as missed approaches in night instrument weather conditions is also vitally important.

WEATHER

The study revealed some interesting statistics relating to weather-related accidents for the glass cockpit fleet, which accounted for a significantly higher number of accidents (15.8 per cent) compared with the GA fleet overall (4.7 per cent).

The most significant finding was that these accidents accounted for nearly half of all fatalities (44.4 per cent) in glass cockpit aircraft compared with 16.4 per cent for the GA fleet overall.

On the other hand, the occurrence of continued VFR flight into IMC, another significant cause of GA accidents, was significantly reduced in the glass cockpit fleet. VFR-into-IMC accidents accounted for about two-thirds of weather-related fatalities in the GA fleet overall, but a little more than one-third for the glass cockpit fleet.

While these accident reports do not provide conclusive reasons, there are several factors that may have contributed to the higher number of glass cockpit weather-related accidents. These include:

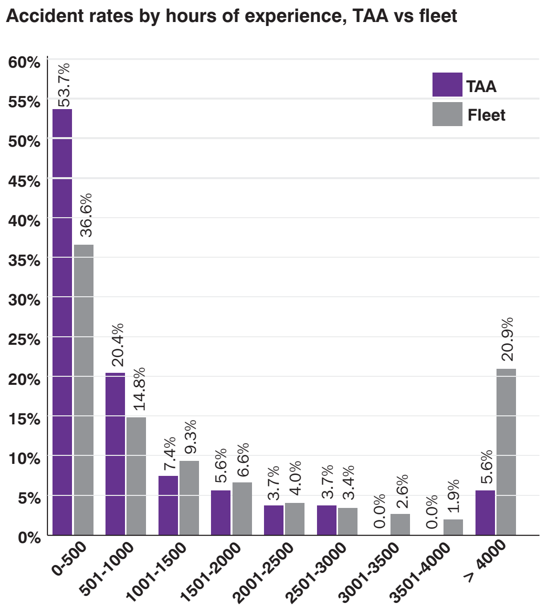
- a tendency for glass cockpit aircraft to be used for cross-country flying, with more time exposed to adverse weather, compared with those used primarily for flight training
- the possibility that some IFR pilots have attempted to use the weather information displayed on the multifunction displays to manoeuvre around weather and 'push on', eventually encountering weather that was beyond their capabilities or that of the aircraft
- an element of poor or inadequate pre-flight planning by pilots who relied on en route weather updates and thus failed to build an accurate picture of forecast weather conditions.

EXPERIENCE

Pilot experience was a significant factor in glass cockpit aircraft accidents. Pilots with up to 1000 hours flying experience in all aircraft types are more likely to be involved in an accident in a glass cockpit aircraft (74.1 per cent of all accidents) compared with the GA fleet overall (51.4 per cent).

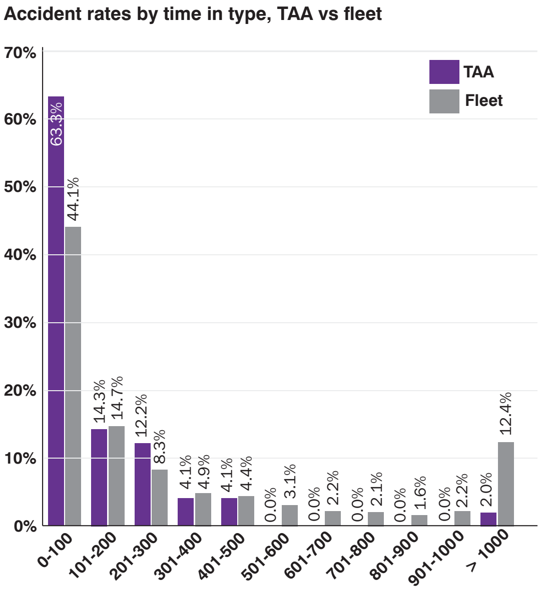
Those with up to 1500 hours were more likely to suffer a fatal accident in a glass cockpit aircraft (87.6 per cent) compared with the GA fleet overall (56.9 per cent).

Figure 18 Accident rates by pilot experience; glass cockpit fleet versus GA fleet overall



The study also found a significant difference in accident rates for pilots by hours on type. Pilots of glass cockpit aircraft with up to 300 hours on type accounted for 89.8 per cent of accidents and 91 per cent of fatal accidents, compared with 67.6 per cent and 67.1 per cent respectively in the GA fleet overall.

Figure 19 Accident rates by experience on type; glass cockpit fleet versus GA fleet overall



Transitioning from analogue to digital cockpits

The US Federal Aviation Administration (FAA), AOPA, researchers, and other industry members collaborated to produce the *General Aviation Technically Advanced Aircraft—FAA/Industry Study*.[24] These findings are equally applicable to the GA sector in Australia, where there has also been research into the challenges of moving between analogue and digital cockpits.[25]

The principal findings were:

- the safety problems identified are similar to problems which occurred after the introduction of other new aircraft technologies, and reflect commonly identified GA pilot judgment errors
- a combination of improved training and better pilot screening have proven to be successful in remedying previous safety problems and can be expected to be equally effective in remedying the safety issues arising from glass cockpit aircraft
- the steps required to call up information and program a GPS approach in glass cockpit aircraft are numerous, and during high workload situations they can distract the pilot from the primary duty of flying
- as with previous experience with the introduction of new technology, the existing training infrastructure must be improved to provide specific training in glass cockpit aircraft
- glass cockpits have the potential to improve safety. However, to realise this potential, and exploit the opportunities of aircraft fitted with them, pilots must receive additional training in these systems and how to operate within their limitations
- the potential for the additional safety features of glass cockpits to address traditional causes of GA accidents (in the US and in Australia) can be realised with improvements in training.

SHADES OF THE BOEING MODEL 299

The introduction of glass cockpit aircraft into GA operations requires a new mindset by pilots transitioning to them.

While it may be possible for pilots to recall from memory all the procedures needed to set up a conventional aircraft for the various phases of flight, it is far more difficult to do so in the glass cockpit. Given the increased complexity of the aircraft systems, and the number of steps and considerations required to be committed to memory, it is more likely that a critical step may be forgotten, or an entire procedure omitted.

As with the introduction of the Boeing 299, it is not that technologically advanced aircraft are 'too much for one pilot to fly,' they may simply be 'too much for one pilot's memory'. If the world's best test pilots require checklists, and the world's airline pilots accept these as a normal (and essential) part of their daily lives, then GA pilots must accept that the use of appropriate procedures and checklists are a vital key to improving flight safety.

INFORMATION OR DISTRACTION?

The advanced technology and automation available in glass cockpit aircraft has the potential to improve situational awareness and decision making. However, the volume of information also has the potential to inform—or distract—the pilot during critical phases of flight. The outcome depends almost entirely on our level of knowledge and understanding of the aircraft systems, and how we manage and respond to the information available in flight.

While the autopilot may be able to fly the aircraft more accurately and efficiently than people can, the automation cannot program itself. In high workload situations, it is often more difficult to program the automated systems to complete a task than to do it manually.

As pilots, we are responsible for management of the flight at all times. We must be ready to disconnect the automation and fly the aircraft manually when appropriate, rather than attempt to program our way out of trouble. Getting bogged down trying to reprogram the flight management system and being 'head down' for some time, may result in a loss of situational awareness. This has obvious safety implications, particularly in the terminal area in proximity to other traffic, in challenging terrain or hazardous weather.

Despite the new and improved technology in glass cockpit aircraft, we must not forget the age-old maxim of '*aviate, navigate, communicate*'. We must practise and maintain proficiency in basic flying skills and be prepared to take over if the automation is not performing as we want it to. The following case study illustrates the danger of distraction.[26]

Near the end of an IFR flight from Jacksonville, Florida, to Greenville, South Carolina, the pilot was advised by ATC that the weather was below approach minimums and was asked if he wanted to divert to his alternate airport. The pilot elected to do so and was given radar vectors for the final approach course.

As the pilot manoeuvred for the approach, the aircraft descended below the minimum safe altitude (MSA) of 2500 ft, at which time the tower controller issued a low altitude warning, with no response from the pilot. Attempts to re-establish communication with the pilot were unsuccessful.

Examination of the crash site revealed a damaged power line about 23 metres above the ground and that the tops of four trees were also damaged. Debris was scattered in an area 30 metres wide by 137 metres long. Post-accident examination of the wreckage failed to identify a mechanical problem or component failure. Radar data showed the aircraft losing 600 ft of altitude in 14 seconds (a rate of descent of more than 2500 ft per minute) before it was lost.

ASF Comments:

This accident appears to be a loss of altitude awareness leading to descent and striking of power lines and trees. Glass cockpit aircraft displays provide excellent depictions of the flight path, desired course, and other data on the navigation display; however, they are less helpful in providing a clear picture of aircraft altitude compared with that desired. Altimeter 'bugs' allow the pilot to set target altitudes, but not all pilots use them effectively. In this case, the pilot may have been reprogramming the navigation system for the newly assigned approach. Such a distraction could result in loss of altitude awareness. Appropriate knowledge and use of the autopilot is essential in these situations.

Charter and GA accidents in Australia

To better understand the effects of design and automation for charter and GA pilots, let's first have a look at the current safety issues, and the current state of the GA fleet in Australia.

According to 2016 figures from the Australian Transport Safety Bureau:[27]

- some 230 aircraft of all types were involved in accidents in Australia
- another 291 were involved in serious incidents
- 15 aircraft were involved in fatal accidents, resulting in 21 fatalities (a record low number)
- 15 of the accidents involved commercial air transport operations, with one fatality (a passenger in a Robinson R44 helicopter).

Nearly half the 393 incidents in the charter sector involved birdstrikes. While the number of incidents was below the 10-year average, the number of serious incidents, 24, was the highest for the period.

There were 11 charter accidents in 2016, compared with three in 2015 and 23 in 2014.

In 2016, the most common accidents and serious incidents in air transport operations were:

- collision with terrain
- loss of control in flight
- crew and cabin safety
- breakdown of separation
- ground operations.

There was a similar pattern for general aviation, but with powerplant issues in lieu of crew and cabin safety, and ground operations.

Historically, other significant causes of accidents in GA include fuel exhaustion, continued VFR flight into IMC, and weather-related events. The advanced technology systems available in glass cockpit aircraft have the potential to address many of these issues and thus enhance flight safety.

With appropriate pilot training and systems knowledge, automated systems such as integrated autopilot and FMS, GPS, real-time weather and terrain displays and TCAS have the potential to improve situational awareness and address the leading causes of accidents in GA.

A recent study has revealed some interesting statistics about the GA and charter sectors in Australia.[28] The average age of the aircraft fleet in these sectors is 32.3 years, while the average age of the largest fleet, single-engine aircraft, is 36.4 years. The most popular single engine models are the Cessna C172 and the Piper Cherokee, with average ages close to 40 years.

This study found that there is a significant ageing aircraft problem in Australian aviation. In 2015, almost 25 per cent of the total GA fleet was unserviceable while undergoing extensive repair or overhaul and upgrades.

Many charter and flight-training aircraft are rapidly nearing the end of their economic life and will need to be replaced in the coming years. It is highly likely that this will result in a significant increase in number of glass cockpit aircraft entering the Australian register, with Australian pilots experiencing many of the challenges identified in the AOPA study.

Considerations for training

We can learn some valuable lessons from the findings of recent research into glass cockpit aircraft and the experience of airline pilots transitioning to them.

The introduction of glass cockpit aircraft by charter and GA operators in Australia will require new piloting techniques, including a more methodical and structured adoption of airline-style checklists and procedures and a high level of flight discipline.

The technological advances of glass cockpit aircraft have the potential to improve safety and address some of the more common causes of GA accidents, including pilot judgment and decision-making errors.

But this potential can only be realised through effective training. Responsibility for implementing the necessary steps must come from the top of the organisation.

It begins with the development and implementation of robust policies, procedures and guidance material, and establishment of an effective training and checking system.

Effective targeted training is needed to improve pilots' knowledge and ability to use this new technology. If they know when to intervene, or revert to lower levels of automation, charter and GA pilots will be able to operate glass cockpit aircraft to their full potential, reaping the rewards of improved efficiency and flight safety.

Pilots must learn to manage automation appropriately. This requires well-designed training, delivered by experienced and knowledgeable instructors, trainers and check pilots. The increasing availability and use of flight simulators and flight training devices creates more opportunities for targeted training.

The final report of the Flight Deck Automation Working Group (FDAWG), a collaborative effort between the FAA and industry groups, included recommendations to improve training and enhance safety for glass cockpit aircraft.[29] The key recommendations that are applicable for charter and GA organisations and pilots can be summarised as:

Policies

- Operators must develop clear and robust policies, procedures and guidelines for the use of automation.
- These policies, procedures and guidelines must be clearly outlined and easily understood, and must be consistent across fleets and types.
- Automation policy should highlight and stress that the responsibility for flight path management lies with the pilot at all times, supported by automation.
- Operators' policies for flight path management must support, and be consistent with, the training and practice in the aircraft type.

Procedures

- Operators must develop and implement standard operating procedures (SOPs) and guidance for the use of automation, including:
  - » use of flight path management systems, including autopilot, autothrottle, FMS, GPS
  - » conduct of the various instrument approaches available, including GNSS, ILS and non-ILS (non-precision) approaches
  - » use of cockpit alerting and warning systems, including expected pilot response to TCAS and GPWS, windshear and terrain warnings, as installed.
- Develop and implement recommended practices and guidance to improve automation mode awareness and understanding:
  - » focus on flight path management rather than automated systems
  - » provide guidance on the appropriate automation modes for certain operations and situations
  - » provide examples of when the autopilot should be engaged and disengaged, or operated in higher and lower authority modes:
    - * provide guidance on the use of various auto flight systems together, including LNAV and VNAV, autopilot and autothrottle (for example autothrottle engaged without autopilot engaged)
    - * give clear guidance on conditions under which the autopilot will or will not engage, and when it may disengage or revert to another mode.

Training

- Operators must develop expected standards and guidance material for maintaining knowledge of automation and manual flying skills, including cognitive and manipulative skills:
  - » pilots must be provided with opportunities to refine the knowledge and practise the skills required to recover from automation malfunctions

- training and checking should address this topic directly during initial and recurrent training. Opportunities should include cognitive and manipulative skills practice and opportunities to train to proficiency.
- operators' training and checking standards for flight path management must support, and be consistent with, automation policy and in accordance with SOPs for each type.

Key points for professional pilots

It is likely that most charter and GA pilots will transition to glass cockpit aircraft as more of these aircraft enter the Australian register, but also that pilots trained on glass cockpit aircraft will fly conventional aircraft.

Advanced automation has the potential to improve situational awareness and decision making, but also has the potential to introduce further errors. The information it provides can both inform and distract us during critical phases of flight. As professional pilots, we need to be aware of potential errors and 'automation vulnerabilities' and maintain a high level of flight discipline.

The key to operating any new technology or automated system is to ensure we have adequate knowledge and understanding of the systems and how they operate, and the limitations of our human performance.

We are responsible for management of the flight path at all times and we must not rely on automation to fix the situation when things start to go wrong. We must be ready to disconnect the automatics and fly the aircraft manually when appropriate, rather than try to program our way out of trouble.

Adequate training and personal study are needed to learn the systems and the appropriate SOPs for normal and non-normal or emergency situations.

To enhance safety and eliminate many of the automation errors we have discussed in this booklet, follow the company or manufacturers' guidelines for the use of automation, and adhere to SOPs including appropriate use of checklists, cross-checking automation modes and operation, and flight path management.

Key points for charter and GA operators

Advances in cockpit automation have the potential to enhance the safety and efficiency of flight operations. Current operators of advanced technology aircraft, and those looking to introduce glass cockpit aircraft into their fleets, must develop and implement clear and concise automation policies, procedures and guidelines to gain the full potential of this technology.

The importance of appropriate training cannot be overemphasised. Operators must address the human performance issues, including the common types of automation errors outlined in this booklet, through appropriate human factors awareness training, and targeted training for the effective use of automation. This training should include opportunities for pilots to learn effective automation management, through appropriate training systems design and delivery by appropriately experienced and knowledgeable instructors, trainers and check pilots.

Initial and recurrent training should include discussions about when to intervene or revert to lower levels of automation, and opportunities to maintain proficiency in manual flying skills, including cognitive and manipulative skills. The increasing availability of flight simulators creates improved opportunities for more effective scenario-based training to improve pilot judgment and decision making, and address the leading causes of accidents in charter and GA operations.

Resources

KEY TERMS

automation Refers to any system of automated guidance and/or control that is capable of altering (either directly or indirectly) the aircraft's flight path or energy state.

flight management system (FMS) Automated flight path management system, controlled via a control display unit (CDU) in the cockpit.

glass cockpit An aircraft with electronic flight instruments (EFIS), displayed on one or more (usually LCD) screens.

global positioning system (GPS) Satellite based navigation system, independent of ground-based aids.

ground proximity warning system (GPWS) A cockpit alerting system that warns pilots of the proximity of the aircraft to terrain—can include other warnings, such as 'glideslope' or 'windshear' warnings.

human-centred automation Automation that seeks to enhance the capabilities and compensate for the limitations of human performance.

human error Errors are defined as actions that fail to achieve their desired outcome without the intervention of chance or other agency or influence.

mental model A mental picture or 'schema' of the (aircraft) situation, formed from collating/processing available information.

mode awareness Refers to situational awareness specific to automation functions. The opposite of mode awareness is often termed mode confusion.

multi-function display (MFD) An EFIS display that combines the ND with engine indications, and radio/communication information, displayed on one (usually LCD) screen.

navigation display (ND) An EFIS display including moving map, usually combined with weather and terrain information, on one (usually LCD) screen.

primary flight display (PFD) An EFIS display of the primary flight instruments, combined on one (usually LCD) screen.

startle An immediate 'reflex' response to sudden, unexpected events; related to the 'fight-or-flight' reaction.

surprise A combination of physiological, cognitive and behavioural responses to an unexpected event. An inability to comprehend an unexpected situation.

technology-centred automation Automation that seeks to overcome the limitations of human performance by replacing human functioning with machine functioning.

terrain awareness warning system (TAWS) A cockpit alerting system that warns pilots of the proximity of the aircraft to terrain.

traffic collision avoidance system (TCAS) A cockpit alerting system that provides warnings of proximity to traffic (other aircraft), and instructions to avoid conflicting traffic (resolution advisory).

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