AVIATION SAFETY

Spotlight

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AVIATION SAFETY THROUGH FUTURE EYES

AVIATION SAFETY **Spotlight**
the aviation safety magazine of the Australian Defence Force

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Sept 2018

Foreword

I would like to take this opportunity to highlight a number of recent changes in the safety world. Firstly, I should introduce myself as the new Director of what was DDAAFS. I have replaced Group Captain John Grime, who heads off to a new and well-deserved appointment as the Officer Commanding 92 Wing. He is currently grappling with the conversion from AP-3C Orion to the new P-8A Poseidon. Grimbo, good luck on 92 Wing, and a well-done from all here for your great work in leading DDAAFS.

That leads me to the next change. After more than a decade known as DDAAFS, we must now change our name. Most of you will know that Air Force Safety (AFS) have moved to Air Command, under the command of HQAC A9. Therefore, our name (which included Air Force Safety – the 'AFS' in 'DDAAFS') no longer accurately describes us. We will now be known as the Defence Flight Safety Bureau (DFSB). This name acknowledges the subtle difference between our role in a 'flight safety' sense, and the broader remit of the Defence Aviation Safety Authority (DASA, of which we are a part) in the 'aviation safety' sense. Finally, our use of the term 'Bureau' aligns us with our maritime and civilian colleagues (MSB and ATSB respectively).

The DFSB will continue to provide the support to all areas which you should expect, such as safety investigations, and hazard reporting. We are focused on ensuring the success of ASR in Sentinel, and will continue to work with you on that. We intend to strengthen our focus on areas such as ASMS policy, research, and exploiting new media for use in safety promotion.

Finally, and somewhat unusually, we have dedicated this entire issue of Spotlight to emerging issues in the field of aviation safety, seen through the eyes of our talented students undergoing training at ADFA. I will hand over to COL Peter J Murphy (PhD) to explain further...

Regards,

GPCAPT Nigel Ward
Director DFSB

INSIDE

Introduction

As I write, the next generation of aviation professionals is being readied across Defence training institutions. These trainees are mostly from the millennial generation, which cops a lot of flak about its work expectations (ambitious) and use of social media (heavy).

Yet there is no doubt that millennials are technologically savvy, they learn fast, and they are keen to develop professionally. These characteristics were amply demonstrated by the 43 students who recently completed the semester-long Aviation Safety course at the Australian Defence Force Academy.

The broad aim of the course is to introduce human factors as an applied discipline and explore its role in support of aviation performance and safety across a range of aviation industry occupations.

The course has a balance of the theoretical and the applied. Students become conversant with concepts such as systems theory, the organisational accident model, and modern precepts of human error. Numerous accident and incident case studies highlight the importance of learning from the past so that we can better address and integrate human factors in support of aviation safety.

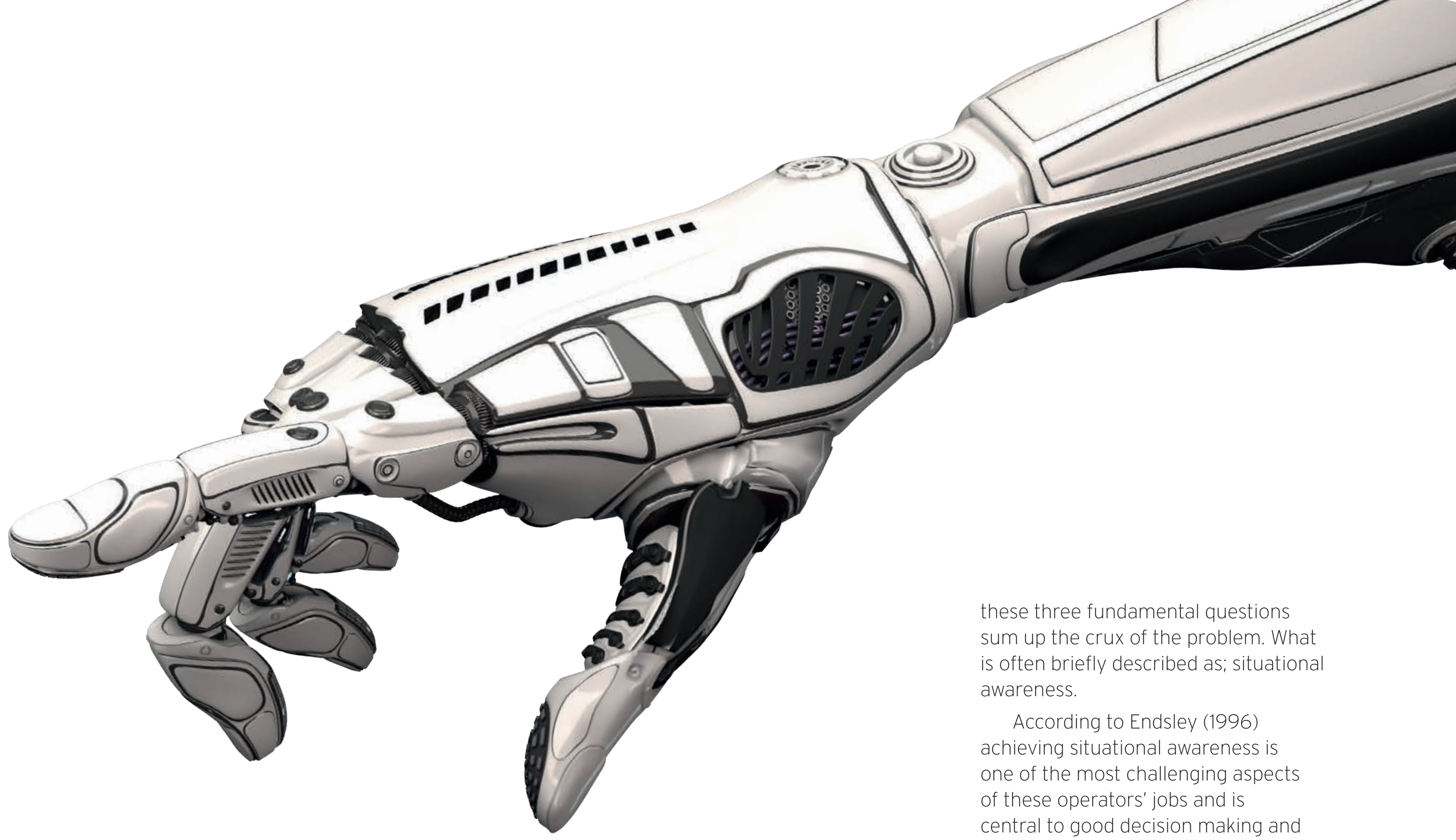
An important learning opportunity on the course was the presentation of seminars, mostly in pairs, on topics as diverse as perceptual illusions, motion sickness, display technologies, flight simulation, human factors in airport security, automation philosophy, air-traffic management, and unmanned aerial systems.

Students also submitted an essay to demonstrate their ability to critically evaluate the scholarly human-factors literature and to deliver an original and engaging perspective based on their research. This edition of *Spotlight – through future eyes* – showcases a selection of these essays. I trust they will provide the reader with an appreciation of how the next generation of practitioners are viewing safety and performance issues in aviation.

COL Peter J Murphy (PhD)
ADFA

Is the human dimension the key to successful automation?

A human factors analysis of modern aviation automation



By Ryan Lake

The field of aviation automation is rapidly expanding and has been continually doing so since its earliest introduction in the mid-1950s. When we consider the data presented on the history of aviation accidents, there is clearly a significant reduction in incidents in the late 50s and 60s (ICAO, 1998). Although not the only factor, the introduction of automated systems aimed at eliminating negative factors on human performance has made a clear impact on aviation safety (Chialastri, 2012).

It is worthwhile to note that past the spike in the mid-'70s, the occurrence rate of aviation incidents has not continued to significantly reduce (ICAO, 1998). Both Oster et al. (2010) and the ATSB (1996) in separate studies of aviation accidents concluded that the pilot was the main causal factor in the accident, suggesting that although automation technology has continued to rapidly improve in both sophistication and reliability.

It has had an apparently disproportionate net result on aviation safety and improving pilot performance. This initially perplexing observation can nevertheless be explained through the analysis of the human factors component or the human-automation co-ordination. This essay will discuss the reasons for concern in this regard, detailing the effects of poorly adapted automation on human performance and how it can occur. It will then investigate the modern aviation-system designer approach towards the human dimension of automation and how that approach has developed over time.

Finally, we will look at what the consideration of human factors discipline can achieve towards perfecting human-automation co-ordination on the flight deck.

Unintended effects on human performance

The basic problems identified with control of an aircraft using a flight-management system can be described by three common questions asked by flight crew; What is it doing?, Why did it do that? and What will it do next? (James et al., 1993). Although there are a number of serious issues that can arise when a system designer neglects to consider the human component of an automated system, these three fundamental questions sum up the crux of the problem. What is often briefly described as; situational awareness.

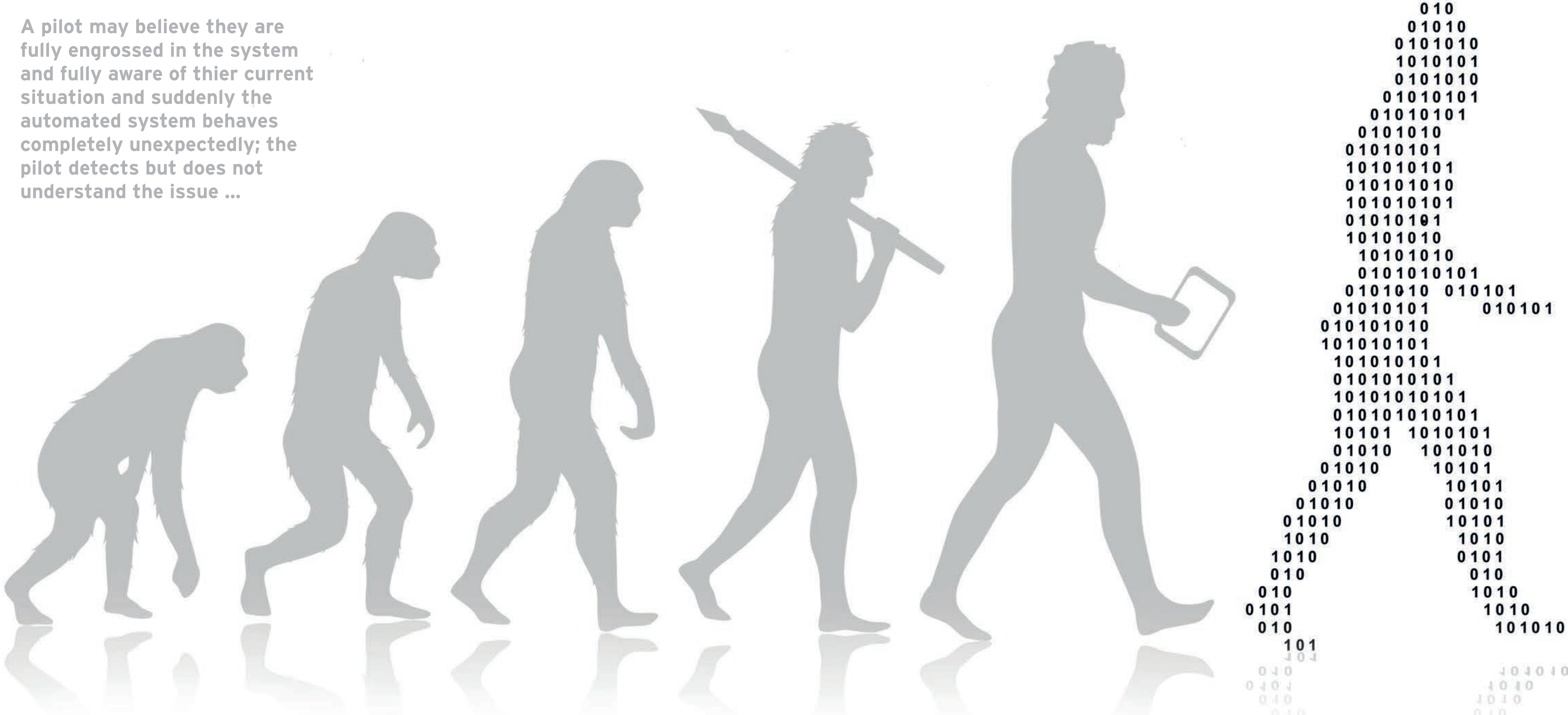
According to Endsley (1996) achieving situational awareness is one of the most challenging aspects of these operators' jobs and is central to good decision making and performance. In that context Endsley is writing with regards to all workers in highly complex and dynamic systems but the application to aviation is seamless and in the context of aviation, when we understand and apply the concept of situational awareness to the system design process; we can achieve truly effective human-automation co-ordination.

For the system designer to safeguard against loss of situation awareness they must understand its causation.

Humans are naturally poor supervisors of highly automated systems that keep them in a state of mental underload. It has been largely reported that mental underload and overload can negatively influence performance (Xie & Salvendy, 2000). What this means is that in a highly automated system, the user is potentially left too little to do in the system process and falls out of the loop.

This out-of-the-loop performance issue is suggested to occur through vigilance and complacency problems, shifting from active to passive

A pilot may believe they are fully engrossed in the system and fully aware of thier current situation and suddenly the automated system behaves completely unexpectedly; the pilot detects but does not understand the issue ...



roles in the system and changes in feedback to the operator (Endsley, 1996). The opposite of this can also occur and instances of extreme mental overload can severely detract from pilot performance. An example of this is Qantas Flight 72, in which an automation error resulted in an extreme number of audio and visual warnings sent to the pilot, some of which completely contradicted other warnings. As such, these warnings intended to assist the pilot, created a significant amount of workload and distraction for the flight crew (ATSB, 2008). This clearly demonstrates a lack of consideration for the human observer of the automated system.

Operators of an automated system have a diminished ability both to detect system errors and subsequently to perform tasks manually in the face of automation failures when compared to workers who manually perform the same task of that automated system (Endsley and Kiris, 1995).

Endsley and Kiris are among many who have conducted studies into the effects of automated systems on human supervisors to discover the significant impact in human performance decreases. Casner et al. (2014) conducted a study specifically to address the concerns on pilot-skill degradation caused by reliance on automation. They found that basic skills such as instrument scanning and stick controls were reasonably maintained but higher-level cognitive tasks such as navigation and recognising instrument system failures suffered frequent and significant problems. They hypothesise that the retention of such cognitive skills may depend on the pilot's level of active engagement while supervising the automation. The findings of Casner et al. are consistent with the three pathways to becoming out of the loop suggested by Endsley, particularly with regards to the necessity of assuming an active role in the automated system.

Automation surprise is another highly vital factor for a modern system designer to be aware of. It is strongly linked to a loss of situation awareness, although subtly and distinctly different.

Automation surprise does not necessarily mean the pilot has experienced any of the detractive pathways suggested by Endsley. A pilot may believe they are fully engrossed in the system and fully aware of their current situation, and suddenly the automated system behaves completely unexpectedly; the pilot detects but does not understand the issue (Dehais et al., 2015).

De Boer & Hurts, 2017 conducted a study into automation surprise into Dutch airline pilots and concluded that Automation surprise seems to be a manifestation of the system complexity and interface design choices in aviation today, nearing the bounds of what is humanely possible to comprehend.

Furthermore, they concluded that lack of knowledge or training were outweighed as factors when compared to the advanced sophistication of the automated systems. This means that the modern designer will need to duly concern themselves with exactly how much complexity a pilot is able to comprehend effectively.

Do aircraft systems designers appreciate the human dimensions of their work?

The safety philosophy behind the adoption of increasing onboard automation is based on the assumption that human error is the main cause of accidents (Chialastri, 2012). If it is the human that is the weak link in the chain should it not be removed? Chialastri argues that pilots and machines should not be substituted for one another but instead be complimentary in order to achieve the correct balance to maximise aviation safety potential.

Although automation has dramatically reduced the occurrence of aviation accidents, that rate has stagnated since the 1980s (Boeing, 2013). Following investigations into accidents around this period it was concluded that the human operator had not been considered as a component of the overall structure when designing the automated system and that no effort had been made to combine the human and machine into a cooperative unit (Dehais et al., 2015).

This has not, however; been at the forefront of designer's minds. In a NASA study of human factors in advanced automated aircraft, (the Boeing B-757) the pilots expressed that they felt the automation left them out of the loop and also found that the automation increased the workload during flight times with an already high workload and decreased during times of low workload (Weiner, 1989). This indicates that aircraft automated system designers did not appreciate the human dimensions of their work or attempt to comply with the human-factors literature being produced at the time.

Since the 1980s there has been a considerable increase in academic literature relating human factors and automation but not so much has translated into actions on the system-designer end. This may be due to a multitude of factors but most markedly, the rapid increase of air travel and the resultant need for reduction of costs related to better performances, lower fuel consumption, cheaper maintenance and flexible pilot training – the main drivers of modern cockpit design (Chialastri, 2012). These factors could explain why we are still yet to observe another marked drop in accidents per million.

Reason (2000) lists four safety paradoxes based on the study of high reliability organisations, the third of which applies to the attitude of aviation automation over past decades. Many organisations seek to limit the variability of human action, primarily to minimize error, but it is this same variability – in the form of timely adjustments to unexpected events – that maintains safety in a dynamic and changing world (Reason, 2000). When applied to the automation of aviation we can see that in many cases the aircraft system designers have fallen, to at least some degree, into this paradoxical trap. Airbus' automation design philosophy in particular demonstrates this, with its automated policing of any flight manoeuvre outside of the safe flight envelope. Thus, showing a greater willingness to trust the autopilot over their own pilot in such an emergency situation.

Perfecting human-automation co-ordination on the flight deck

To perfect human-automation co-ordination requires a willingness from aircraft system designers to commit significant research into the way in which their pilots interact with the automation of their aircraft.

Modern aircraft have come a long way in addressing the majority of the safety issues related to aviation and automation is becoming so advanced that the idea of completely designing the pilot out of commercial cockpits is fueling market feasibility research. Yet even unmanned flight is plagued with human-automation co-ordination issues, a report on aviation accidents among UAVs of the US military found that up to 47 per cent of accidents per airframe where human factors related (Williams, 2004).

The answer lies in designing the system around the human, rather than inserting the human into an ill-fitted system as has been done in the past. System designers must consider the effect a highly automated system can have on the supervisor and adapt to mitigate those effects from the earliest design phase.

Creating a system that is adaptive and actively engages the pilot in periods of low mental workload but is also able to intuitively take up tasks in times of high mental workload will likely be the way forward. However, adaptive automation itself is not a simple matter and a myriad of elements must be considered in order not to create its own human-factors problems (Endsley, 1996). The exact method for implementation of adaptive automation requires significant study and automated system designers should make it a critical point for further research.

Other points of improvement are easier to approach. This could include creating a system to encourage the pilot to behave in an active manner when monitoring, as shown by Casner et al. (2014), this will likely benefit cognitive skill retention. Furthermore, the drop in situation awareness brought on by changes in feedback to the operator is easily combatable through a robust user interface designed to provide feedback that is informative and easily digestible by the pilot. It should provide the information in such a way as to not drastically increase the mental workload on the pilot and thereby reduce his performance.

What this means is that in a highly automated system, the user is essentially left too little to do in the system process and falls out of the loop. This out-of-the-loop performance issue is suggested to occur through vigilance and complacency problems, shifting from active to passive roles in the system and changes in feedback to the operator (Endsley, 1996).

Conclusion

It must be noted that little or no systematic attempt has been made to design and implement automatic systems in relation to the needs, capabilities and limitations of human performance (Edwards, 1977). As illustrated by Edwards, concern for mitigating the inadvertently negative impact that automation can have on the human component and by extension, human performance, has existed for many decades of high-level automation aviation.

In 1977 Edwards wrote a journal article stating the lack of human factor consideration in system design; in 1991 NASA released *Human-centered aircraft automation: A concept and guidelines* to direct their organisation, and even in 2018 books are being written on the same subject. As exemplified by this the human-factors approach to automation is one that has been discussed throughout the entire history of its use.

It is clear from the analysis of the sources that system designers are aware of the need to appreciate the human dimensions of their work, although translating this knowledge into tangible results has thus far been of modest success.

Inarguably, automation has had a significant impact on the reduction of aviation safety incidents and will likely continue this trend far into the future. However, we can see that the application of human factors to the improvement of human-automation co-ordination may succeed in finally closing the gap in automation safety.

Only if we consider the human factor and take a human-centered approach to system design, can we achieve the greatest success in its application and attain zero accidents per million takeoffs. In conclusion, it is considering, analysing and perfecting the human dimensions of the flight deck that is key to successful automation.

ABOUT THE AUTHOR

MIDN Ryan Lake is an undergraduate studying a Bachelor of Science majoring in Aviation and Chemistry at the University of New South Wales Canberra. He is keenly interested in modern aviation safety and the human factors discipline. Most notably in optimising the human performance effects of advancing aviation technologies.

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AUTONOMOUS AVIATION

LEARNING FROM THE GROUND UP

By Max T. Pickering

Across the globe, the aviation industry employs about 500,000 commercial pilots. According to recent reports, there is a requirement for more than 600,000 new pilots in the next 20 years. This is accounting for a growing retirement rate of an aging generation of professional pilots, as well as the steady growth of airline travel across the globe (Gabriel, 2017). This means that more than half of the pilots that will be flying by 2027 have not started training yet (CAE Inc, 2017). These new pilots are receiving less training and will have less flight experience than their retiring counterparts.

Previous pilot generations, due to the large draw from military pilot pools and differing training methods, had a reserve of technical aeronautical knowledge, which has led to the safety culture of the aviation industry that can be observed today. The technology that is implemented by these experienced pilots, such as autopilot features, has been done with an underlying assumption that the pilot is able to utilise the capability that the technology provides them in order to make safe decisions about flight operations (Sinnett, 2017).

If new pilots do not have the experience and proficiency of the pilots of today, a technical solution is required in order to maintain the safety standards of the industry. This technical solution may be one where the aircraft has the capacity to make active decisions about flight. This is called autonomy and its rapid development is currently occurring in the automotive industry. How can aviation learn from this development in order meet the rapidly changing requirements of a growing industry?

Autonomous cars

Autonomous motor vehicles (ATMVs) are set to revolutionise the automotive industry, presenting dramatic economic and safety advantages. According to the World Health Organization (2015), worldwide road traffic deaths sit at about 1.25 million per year.

In a study by the U.S. Department of Transportation (2008), found that human error is the critical reason for 93 per cent of crashes. Thus, the prospect of removing humans from the driver seat is tantalising. Since 2015, autonomous cars have been approved for testing on public roads in several US states. In November 2017, Waymo, the autonomous vehicle division of Google's parent company – Alphabet – put a fully autonomous minivan on a public road without a safety driver (Hawkins, 2017). In order to understand this progress, ATMVs can be measured on a five-level system designed by the Society of Automotive Engineers (SAE). Level zero is a vehicle with no driving automation.

Level 1 is limited driver assistance such as cruise control. Level 2 is partial driving automation such as adaptive cruise control and lane assist. Level 3 is a conditional automation, perhaps automated low-speed freeway driving. Levels 4 and 5 are full automation, with Level 4 being limited to a specific area and Level 5 being unlimited to where it can drive (Society of Automotive Engineers, 2014).

Currently, the leading edge of ATMVs are somewhere around Level 4. If Level 5 ATMVs can become commercially available and well-integrated into all facets of transport, from legislation to cultural acceptance, it is very possible that safety incidents on the road could essentially be eradicated (Stadler, Brenner, & Hermann, 2018).

State of autonomy in aviation

When it comes to autonomy in aircraft, the most modern of passenger airliners has a complex autopilot system that is able to control taxi, take-off, climb, cruise, descent, approach and landing.

There are no operational aircraft, civilian or military, with the capacity to make decisions while flying (Austin, 2010). Most autopilot systems mean aircraft are equivalent to Level 2 or 3 of vehicle autonomy.

While ATMVs utilise camera and sensor systems to build a picture of the road for the vehicle to process and make appropriate decisions about driving, most autopilot systems that are currently in operation utilise internal sensors and cannot assess surroundings. For example, if an aircraft is on approach for an instrument-aided landing, it can divert from the auto-land procedure because of a technical malfunction. However, if another aircraft crosses the runway, the aircraft landing has no perception of the event and the auto-land must be diverted by the pilot (Sinnett, 2017).

An ATMV is more advanced in its capacity to make a similar decision as its outward facing camera and sensor technology can detect a threat and make changes to its operation in order to avoid it (Kichun, Junsoo, Dongchul, Chulhoon, & Myoungho, 2014). Thus, as autonomy becomes more advanced and commonly implemented, the aviation industry could see similar safety and economical advantages that are being seen in ATMVs. Hopefully, the aviation industry can learn from the challenges being faced by ATMV introduction and utilise lessons learnt for a smoother introduction of the technology into aviation.

Driver becomes the driven

Just as the role of drivers is changing with the introduction of ATMV technology, making them into safety monitors of that technology, the role of pilots is likely to change with the introduction of autonomation. There are several ways that the aviation industry could make the journey from A – today – to B – a world where all aircraft are fully autonomous. Stepping stones that may allow this journey could be through augmenting crews of aircraft or changing the decision-making roles within the aircraft (Sinnett, 2017).

If crews were to be augmented, it is conceivable that cargo operations could be done by a single pilot, who would monitor the autonomous technology. In a similar way, long-haul passenger flights could be completed by far fewer pilots, cutting down both the need for pilot volume and experience. No longer would pilots be required to fly the aircraft. Instead, they would act to monitor the safe operation of the autonomous system while being a back up for active decision making.

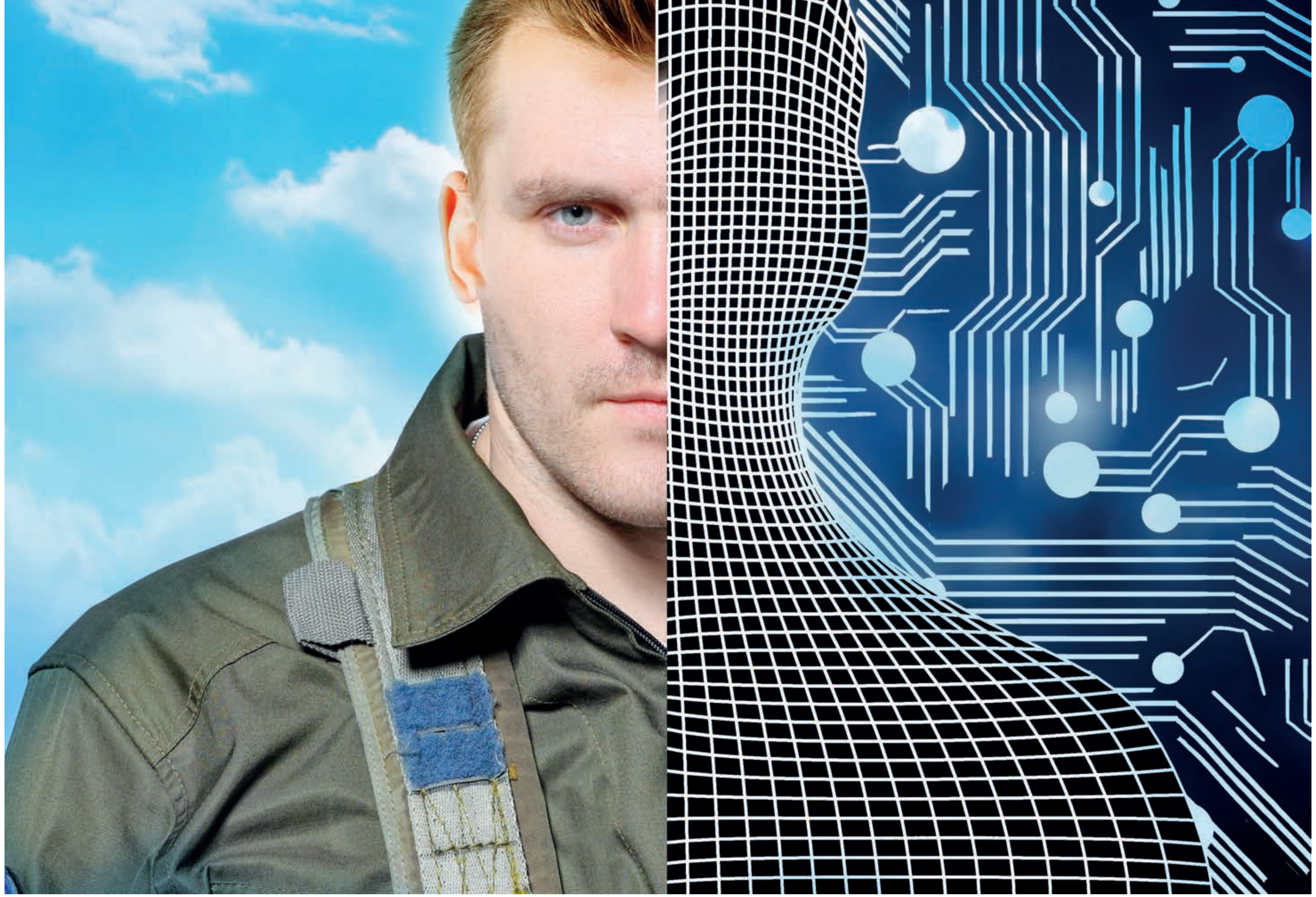
Alert! Alert!

There are challenges in the field of human factors that need to be addressed in the transition to autonomous aviation. These must be overcome while maintaining the safety, integrity and economic stability of the industry.

The human-factors considerations of the aviation industry are comparable to those being made by teams introducing ATMVs into the market. One significant challenge lies in the differing approaches to a human-machine interface, particularly in relation to take-over requests and alerts.

At lower levels of automation, drivers can hand over driving tasks to the ATMV but must be ready to resume at all times. At higher levels, the system must be alert and able to recognise its own limits and hand over to the driver. When this happens, the driver must be ready to take control in a timely manner. Manufacturers are working on the safest way to alert a driver in an emergency with a combination of aural and visual methods (Stadler, Brenner, & Hermann, 2018).

When designing this take-over request, the Chair of Ergonomics at the Techincal University of Munich, Germany conducted an empirical study measuring the ideal take-over alert timing (Gold, Dambroeck, Lorenz, & Bengler, 2013). They found that with alert timings of five and seven seconds, those with five seconds responded with imprecise and unsafe driver actions. However, those with seven seconds had a longer reaction time to respond to the threat. In another study, different driver distractions were analysed (Radlmayr, Gold, Lorenz, Farid, & Bengler, 2014). It was found that those visually distracted with activities such as emailing caused more collisions than those who were cognitively distracted with activities such as conversation with other passengers. These considerations will need to be applied to autonomous aviation. In the transition period, before Level-5 automation can be achieved by aircraft, pilots will still need to respond to take-over requests. Thus, the stimulation of the pilot will need to be managed by aircraft systems in order to maintain a safe take-over response.



Not just anti-virus

Since the 11 Sept 2001, the security of aviation has been of significant concern to legislators and the public. With the introduction of automated aircraft, the connectivity of the system creates vulnerabilities to cyber-attacks. As the technologies advance, the vehicle-to-vehicle and vehicle-to-infrastructure connectivity will complicate the cyber environment and create vulnerabilities in the system (Ben-Noon, 2018). ATMVs are currently overcoming cyber security threats with high-security systems that are regulated by the United States National Highway Traffic Safety Administration. Of particular note, reducing the components of the vehicle that communicate with the outside world reduces the cyber-attack surface of the vehicle, reducing the risk of a breach in security (Stadler, Brenner, & Hermann, 2018).

Automotive manufacturers are developing ATMVs with cyber-security as a fundamental cornerstone of their philosophy and it is a way of thinking that must be adopted by the aviation industry prior to the introduction of vulnerable automation technology.

Trolley problem in the sky

Consider for a moment the hypothetical situation (Lin, 2015):

A large autonomous vehicle is going to crash and hit a minivan with five people inside. If it hits the minivan, it will kill all five passengers. However, the autonomous vehicle recognizes that it may be able to collide with a sports car in such a way that it reduces the impact on the minivan, sparing minivan's five passengers. Unfortunately, it would kill the one person in the sports car. Should the autonomous vehicle be programmed to first crash into the roadster?

This problem closely resembles the trolley problem (Thomson, 1976). Thus, for it to be logically consistent, it must be accepted that the ATMV has all empirical data required to make a certain decision about the outcomes of the two choices.

While there is vast amounts of literature and understood norms around decision making under empirical uncertainty seen in De Groot's Optimal Statistical Decisions (2004), there is no agreed upon framework for moral decision making with empirical certainty. Some ethical researchers suggest that two ethical theories be applied – deontology and utilitarianism (Meyer & Beiker, 2014).

Because of these competing moral decision-making frameworks, a programmer working on the case above cannot program a vehicle based on one particular framework. The competing decision-making values mean that a programmer would need to assign moral weighting to each outcome and come to an ethical conclusion based upon their own moral assumptions and understanding of analogous ethical questioning. This process is called Problem Intertheoretic Value Comparison (PIVC) (Lockhart 2000; see also Sepielli 2006, 2009, 2013; MacAskill, 2016).

ATMV programmers are overcoming ethical competition with averaged PIVC across a team of specially recruited ethical specialists. Since there is no objective trough by

Another legislative challenge lies in the liability of an ATMVs actions. In general, those who are at fault for harm, particularly that which could have been avoided, are punished by the law. By this principle, legal liability is necessary as it is crucial in "advancing the general welfare of society"

which ethical decision making can be made, the autonomous car ethical debate has led to an embrace of ethical complexity where complexity is required (Millar, 2017). This way of thinking about ethical questioning needs to be transferred when autonomous aviation is developed in the near future.

Without a method of overcoming ethical questioning, programmers cannot progress autonomous technology, thus the challenges that have been overcome by ATMV development can be subverted by using PIVC in autonomous aviation programming. This will lead to faster development and implementation of autonomous aviation in comparison to ATMVs.

Who is to blame?

Having overcome most ethical, human factors and safety concerns, the major challenge faced by ATMV development today is a regulatory one. One concern of legislators is that the regulatory authorities that govern safety concerns of motor vehicles do not have the capacity to certify whether an ATMV is safe for operation (Wood, Chang, Healy, & Wood, 2012).

Most current safety statistics for ATMVs come from manufacturers, but regulatory bodies have lost faith in their ability to self-regulate in the wake of the emissions scandals in recent years (Ganser & Wegener, 2017).

Another legislative challenge lies in the liability of an ATMVs actions. In general, those who are at fault for harm, particularly that which could have been avoided, are punished by the law. By this principle, legal liability is necessary as it is crucial in "advancing the general welfare of society" (White & Baum, 2017).

In the automotive industry, engineers and designers are likely to be most liable for harm caused by ATMVs. ATMV liability has posed significant legal challenges to the introduction of the technology and it is a challenge that autonomous aviation is likely to face.

Hopefully a legal precedence has been set by the automotive industry prior to autonomous aviation being fully introduced so that the precedence can be transferred across to the realm of aviation.

What now?

With a growing pilot shortage, the aviation industry needs to make a change. In the next 10 years, there will not be enough pilots to facilitate rapidly growing industry. So, manufacturers are turning to ATMVs – the future of the automotive industry – for inspiration. While there are ethical, human factors and safety challenges that are still to be overcome by developers of ATMVs, autonomous vehicles will surely be common place in the near future.

The technology and lessons learnt from the automotive industry will help aviation to follow down a similar path. Aviation is about to change. Ironically, with or without autonomous systems, the way people think about flying and flight safety will dramatically shift over the coming years. However, without autonomy, the less experienced pilots of the future are likely to degrade the safety culture that facilitates the highly safe operation of aviation that exists today.

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The autonomous car industry and its relevance to aviation

By Brae Harvey

Over the past few decades, the aviation industry has witnessed a movement of de-crewing, with increased on-board automated assistance and even proposals to reduce short-range crews to single pilots (Harris, 2011, p. 222).

Concurrently, research and development into land-based autonomous vehicle (AV) technology has significantly progressed, with companies such as Google promising to improve road safety in which 94% of accidents are caused by human error (Francesca et al., 2017, p. 8). So much so, AVs are listed in the top 10 disruptive technologies of the future (Bagloee et al., 2016, p. 285).

It is, therefore, both reasonable and sensible for aviation stakeholders to learn from the issues surrounding the introduction of autonomous cars. This paper, after briefly defining autonomous in relation to vehicles, will investigate the current safety of today's autonomous cars, including issues surrounding sensors and the security of data, and how they can apply to aircraft.

Human factors, and the effect it has on vehicle design in order to mitigate complacency while maintaining trust in the autonomous system, will also be analysed. Finally, ethical concerns such as the use of forced-choice algorithms, legal matters and job loss will be looked into, and how the aviation industry can learn from such issues.

Automation can be defined as a device or system that is capable of completing a task previously carried out by a human operator (Parasuraman et al., 2000, p. 287). However, for AVs, the Society of Automobile Engineers (SAE) have defined six levels of automation (Litman, 2018, p. 4). Levels zero, one and two include no automation, driver assistance, and partial automation respectively (Fleetwood, 2017, p. 532).

Levels 4 and 5 are deemed high automation and full automation respectively and involve the system performing all driving tasks in all scenarios (Fleetwood, 2017, p. 532). However, most manufacturers are currently focusing on level-3 automation, in which the human only intervenes if required. Although the only current level-4 vehicle in operation is the ParkShuttle system (Lohmann & van der Zwaan, 2017, p. 6), companies such as Tesla and Uber are in the process of researching level-5 vehicles (Wade, 2018).

Current safety

The current use of AVs is limited, and statistics show that conventional vehicles are still safer than AVs. In the United States, conventional vehicles cover an average of 500,000 miles before encountering a crash, while AVs cover only 42,017 miles before a crash (Francesca et al., 2017, p. 18). However, it is important to note the reasons for each AV crash. Out of the 26 accidents between September 2014 and March 2017, the AV was at fault for only four of these. Two of these four accidents occurred while the AV was in manual mode in which the human was driving (Francesca et al., 2017, p. 15). Therefore, if we are to account for just the two accidents in which the AV was both at fault and in autonomous mode, the accident rate is 1,008,408 miles per accident, thereby corroborating with manufacturers' claims that AVs can indeed potentially improve road safety. However, AVs may increase particular types of accidents if the driver relies too heavily on them (Anderson et al., 2014, p. 16). The main current accident type for AVs are those that are hard to detect, predominantly being rear-end collisions that the AV didn't detect in time (Francesca et al., 2017, p. 16). Therefore, as AVs will continue to share roads with non-AVs in the immediate future, the crash rate will never be zero (Bagloee et al., 2016, p. 298). This fact needs to be noted by the airline industry, in which although autonomous technologies may be capable of preventing most accident types, they can still fail to detect and respond to imminent collisions in which another vehicle is at fault.

Mitigation strategies would, therefore, have to be researched and imposed, especially if autonomous aircraft (of levels 3 and above) share an environment with human operated aircraft.

Another problem of AVs is that of road infrastructure. In a system that relies highly on sensorial data, incomplete data could arise, for example, due to not knowing the geometry of the surrounding lanes (Bertolazzi et al., 2014, p. 257). Illusions that can be picked up easily by the human eye cannot be easily replicated by sensors.

A vehicle leaving a roundabout in the opposite lane may be interpreted by the AV sensor as intersecting its own lane (Bertolazzi et al., 2014, p. 257). Therefore, infrastructure regulations will need to be enforced, and objects such as road signage must be standardised (Infrastructure Partnerships Australia, 2017, p. 15). As road networks are often owned and maintained by all three levels of government, such regulatory discussions may take time (Infrastructure Partnerships Australia, 2017, p. 15). The airline industry needs to make note of this. For example, the International Civil Aviation Organisation (ICAO) may need to amend some regulations to accommodate for more autonomous aircraft, as well as heavily enforce such regulations.

Airport operators will need to ensure that taxiways signs are well maintained to ensure sensors can easily identify correct routes. Another concern that was raised by AVs is the visibility of the vehicles themselves. The main cause of a Tesla AV crash was that the sensor could not differentiate between the sunlit sky and a large white truck crossing in front of it (Saripalli, 2017, p. 3). Aircraft may therefore have to be designed with a specific livery so they can be picked up by sensors.

An often overlooked safety issue that has come about from the introduction of AVs is cybersecurity. In a vehicle that relies on computers and sensors for safe driving, software system security must be addressed, especially as cybercrime technology develops (Bagloee et al., 2016, p. 298). The cyber threat is apparent for both the operation of AVs as ad-hoc vehicles, as well as their communication capabilities as connected automated vehicles (Bagloee et al., 2016, p. 298). It would be disastrous for cybercriminals to introduce fake messages into either one of these two frontiers, as it would prompt inappropriate reactions (Bagloee et al., 2016, p. 298). The airline industry, if it were to progress into more autonomous systems in which both the aircraft and the infrastructure are connected, will need to look at how to mitigate such threats.

Human factors

From a human-factors perspective, an issue raised by AVs is how to design one that allows the driver to understand its limitations and capabilities, while maintaining situational awareness of what the vehicle is doing within its environment (Cunningham & Regan, 2015, p. 2). Automatic disengagements are those resulting from a system failure, such as improper sensor readings (Bliss, 2018). Such disengagements require the driver to take control of the vehicle immediately, and therefore pose a risk if the driver is inattentive and distracted (Bliss, 2018). There exists a close link between complacency, attention, and trust (Manzey & Parasuraman, 2010, p. 388). The National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) defines complacency as "self-satisfaction that may result in non-vigilance based on an unjustified assumption of satisfactory system state" (Manzey & Parasuraman, 2010, p. 382).

The AV and airline industries must therefore address the problem of how to create trustworthy autonomous systems, while minimising complacency due to this high level of trust. Studies have also shown that boredom can result from low workloads provided by automation, in which drivers are more likely to engage in secondary activities and look away from the road instead of monitoring the AV (Cunningham & Regan, 2015, p. 2).

It is vital for the airline industry to examine how AV manufacturing companies solve these issues, such as how they design machine interfaces, and how they position the driver in relation to the cabin in order to increase driver attention. This is particularly pertinent as pilots have, in the past, "failed to intervene and take manual control" when automation systems failed (Lee, 2004, p. 50).

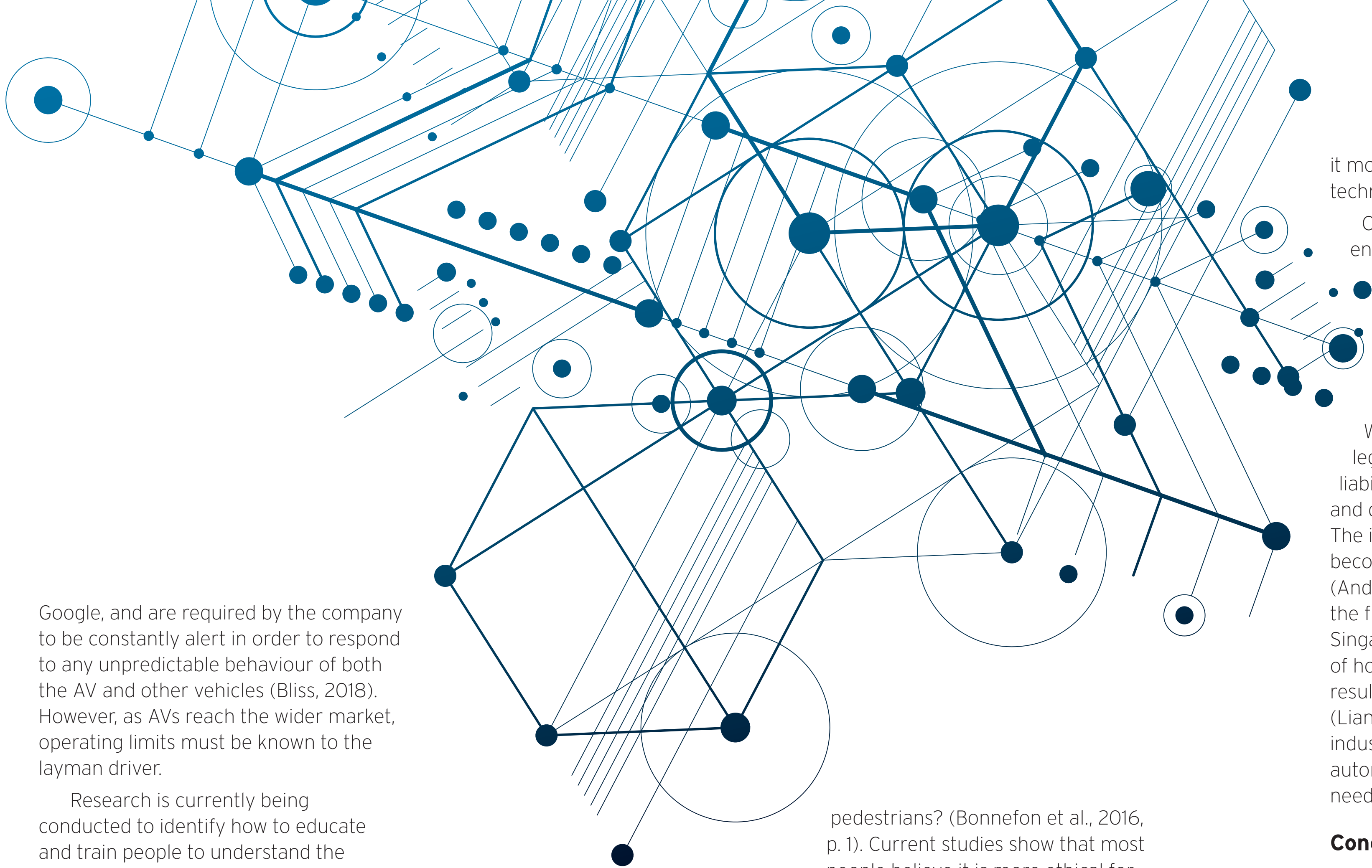
Some studies have been conducted in the AV industry that investigate how different interfaces communicate automation status and limitations. As mentioned above, these studies are of vital importance as it is paramount for the driver to not fall out-of-the-loop (Cunningham & Regan, 2015, p. 5). Results from the Likert scale exposes a clear benefit that auditory feedback has in comparison to no auditory feedback, with drivers unanimously agreeing that auditory signals enhanced their awareness of the vehicle's actions (Beattie et al., 2014, p. 7).

Conversely, having no auditory signals significantly reduced the driver's sense of control over the vehicle (Beattie et al., 2014, p. 9). It is important that signals are timed appropriately, early enough to give the driver enough time to react but not too early so that it may be interpreted as a false alarm (Cunningham & Regan, 2015, p. 5). Driver state assessment (DSA) technology is one such mitigation strategy being used in the AV industry, in which the driver's alertness is constantly monitored by inference of the eye-gaze direction and degree of head rotation (Cunningham & Regan, 2015, p. 6).

DSA technology could have prevented a recent incident on the night of 18 March in Arizona. Investigations into that incident revealed that the operator of the Uber AV was looking down with her hands off the wheel when the car struck a pedestrian (Bliss, 2018). It is therefore practical that mitigation strategies such as DSA be considered in the airline industry if it were to progress to higher levels of automation.

Regardless of the interfaces used, there still exists a need to teach drivers the limitations of AVs. Currently, only well-trained test drivers monitor AVs of companies such as

The National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) defines complacency as "self-satisfaction that may result in non-vigilance based on an unjustified assumption of satisfactory system state"



Google, and are required by the company to be constantly alert in order to respond to any unpredictable behaviour of both the AV and other vehicles (Bliss, 2018). However, as AVs reach the wider market, operating limits must be known to the layman driver.

Research is currently being conducted to identify how to educate and train people to understand the limitations of the AV in order to avoid complacency (Cunningham & Regan, 2015, p. 6). In one study, it was shown that drivers had insufficient knowledge of the limitations of the adaptive cruise-control system, which resulted in inappropriate levels of trust (Helldin et al., 2013, p. 210). Other studies show that different people employ different decision-making strategies and are influenced by different considerations when using automation (Parasuraman & Riley, 1997, p. 235).

Skill degradation is another issue that has been studied by AV manufacturers. Indeed, the neglect of driving skills can degrade the dexterity and cognitive skills required to manually drive safely (Cunningham & Regan, 2015, p. 4). Although the training of pilots is vastly different to that of drivers, the aviation industry should note the potential issues that skill degradation and a lack of training for higher levels of automation can cause.

Ethical issues

Autonomous technology creates many ethical issues. Like any transportation vehicle, including aircraft, AVs need to balance safety, legality and mobility; and must resolve situations in which these come into conflict (Fleetwood, 2017, p. 534). For example, a conflicting safety objective may be produced when addressing the safety of the AV's occupants against that of another vehicle's occupants (US Department of Transportation, 2016, p. 26). Similarly, legal objectives can conflict with mobility and safety objectives, such as when the AV requires to illegally cross a double yellow line in order to avoid a parked car (US Department of Transportation, 2016, p. 25). Therefore, forced-choice algorithms will need to be programmed into AVs (Fleetwood, 2017, p. 534), and if aircraft were to progress to higher automation levels, such algorithms would also apply to them.

Software engineers must attempt to mitigate many different scenarios (Goodall, 2016), and have tough ethical questions to solve. For example, should an AV sacrifice its own occupant in order to avoid harming several pedestrians? (Bonnefon et al., 2016, p. 1). Current studies show that most people believe it is more ethical for AVs to sacrifice its own occupants to save a greater number of lives overall (Bonnefon et al., 2016, p. 3). However, respondents to the same study indicated a significantly lower likelihood of purchasing an AV which is designed to do just this (Bonnefon et al., 2016, p. 4).

Community involvement is vital to ensure AVs are designed appropriately. Public health policies and programs associated with the AV industry must incorporate a variety of approaches that both anticipate and respect the views of the community (Dillenberg et al., 2011, p. 1058). Therefore, processes to ensure opportunities for community input must be put in place (Fleetwood, 2017, p. 533). It is also vital for ethically justified regulations to be developed consistently for each AV manufacturer, and that such regulations are codified by government agencies and monitored effectively (Fleetwood, 2017, p. 536). Such regulations are important to ensure consumer trust and acceptance for AVs. This would also apply for the aviation industry as it moves towards further autonomous technology.

Organisations such as ICAO must ensure any forced-choice algorithms are consulted with all aviation stakeholders, as well as government agencies and the wider public. Other ethical issues arising from the introduction of AVs are legal responsibilities. Will the decisions made by AVs be legally protected, and how much liability will be placed on manufacturers and drivers? (Fleetwood, 2017, p. 534). The issue of employment loss is also becoming an issue for the AV industry (Anderson et al., 2014, p. 39). In 2016, the first autonomous taxi debuted in Singapore and revealed the potential of how autonomous technologies can result in transportation sector job losses (Liang & Durbin, 2016). If the airline industry were to ever progress to fully autonomous aircraft, such issues will need to be addressed.

Conclusion

The aviation industry must be cautious while it develops advanced autonomous systems. As seen by the introduction of AVs, such autonomous systems produce many challenges. Safety statistics for AVs reveal that, although they have the potential to reduce fatalities, they can increase certain types of crashes. The aviation sector must therefore investigate and mitigate the types of scenarios in which autonomous systems are vulnerable. The introduction of AVs has also reasserted the prominence of human factor issues for autonomous systems. Interface design, as well training systems, will need to be adjusted in order to accommodate for such systems.

Ethical issues are currently being researched by stakeholders within the AV industry, such as how to develop forced-choice algorithms. The aviation sector must carefully observe the results of such investigations and apply them appropriately to the design of aircraft. In many respects, the AV industry is paving the way for more advanced autonomous systems in aircraft. It is paramount for aviation stakeholders to keep watch of AV developments in order to ensure the continued safety of aircraft passengers and pilots alike.

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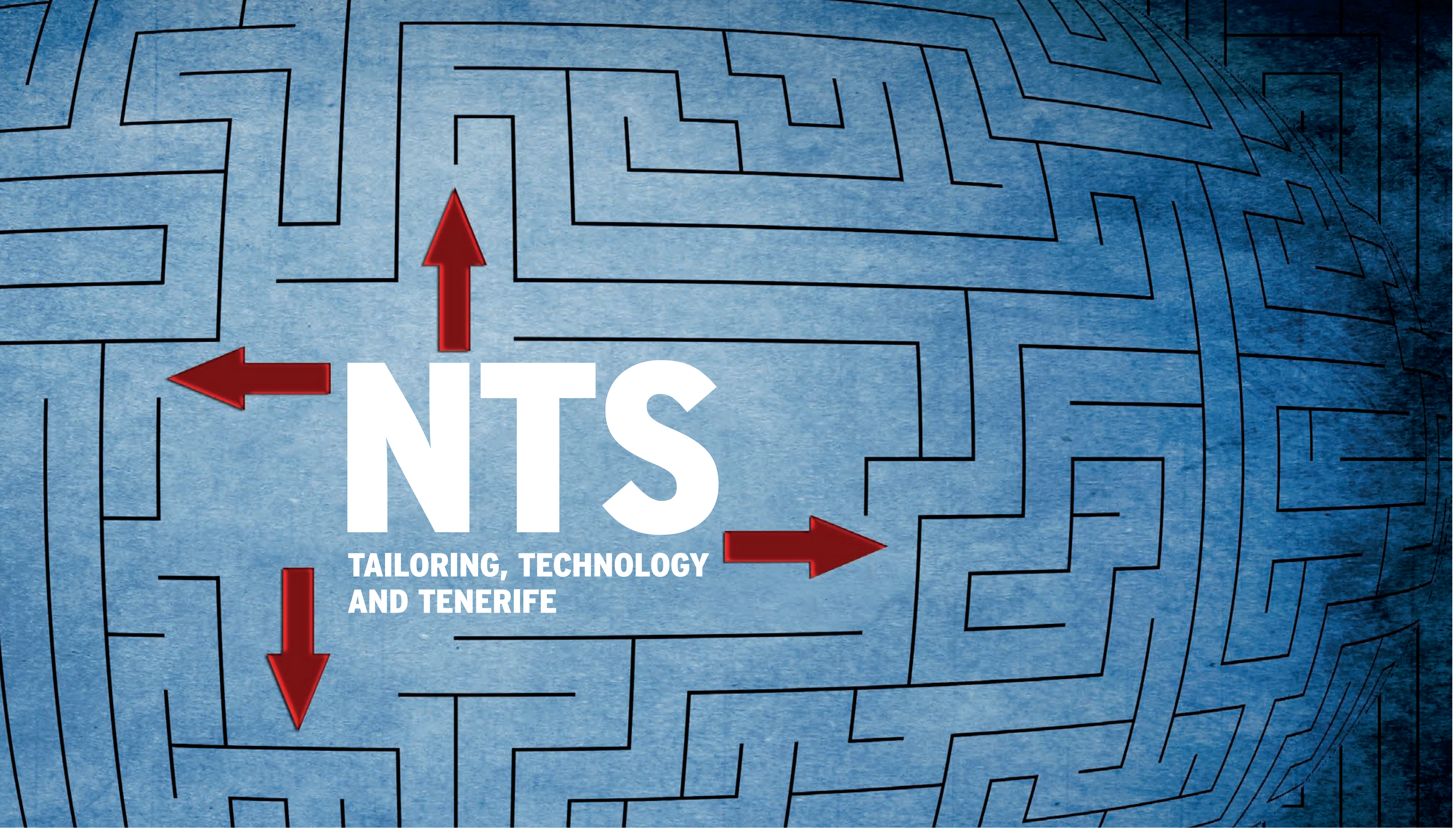


NTS

TAILORING, TECHNOLOGY AND TENERIFE

By Mathew Schmidt

As modern hardware and software systems become more redundant, rigid and reliable, the frequency of human error becomes more apparent. Studies have found that a 50 per cent increase in safety will bring a 12 per cent increase in productivity (Stewart & Townsend, 2000), and according to Harris (2011) "it is estimated that up to 75 per cent of all aircraft accidents now have a major human factors component" (p.5).

Human safety factors of any organisation is in the interest of all, safety appreciation and subsequent mitigation has been studied extensively for many years. Whether working alone or in a team, Non-Technical Skills (NTS) are exercised routinely when made to manage error. Crichton (2008, p. 1), best defines NTS as "the cognitive, social and personal resource skills that complement technical skills, and contribute to safe and efficient task performance."

When NTS training has its limitations identified and mitigated, safety will improve in the respective domain. An organisation that enables a dynamic safety evolution process and adapts to changing technology, can promote safe and efficient task performance. The purpose of this essay is to analyse the history of NTS training through analysis of Crew Resource Management (CRM) and Line Operations Safety Audits (LOSA). The current status of CRM will be put into context with examples of adaptation in modern day policy and its parallels in the modern Intensive-Care-Unit environment. Individual adaptability issues and problems with evaluating NTS training outcomes will be explored as potential limitations. Finally, analysis of its strengths as an exportable product when coupled with a conducive crew-selection program will be undertaken, with future technological challenges considered.

Current status: NTS training and evaluation

To understand the current form and effectiveness of NTS training, context must be given to the changes made throughout its short history. Over time, training has been established and evolved to equip crew with the required social tools to effectively manage themselves, as well as their team.

Research of aviation accidents and incidents (Helmreich, Merritt & Wilhelm, 1999) and airline intrinsic investigations (Burger, Neb & Hoermann, 2002) provided evidence of operational safety breaches due to a lack of non-technical skill, namely: assertiveness, situational awareness and poor decision making. As a result, two leading, non-static, human factor-mitigating initiatives were implemented; namely CRM (Weiner et. Al., 2010) and LOSA (Kinect, 2006).

CRM: history, application and current status

Helmreich (2010) defines CRM as "optimising not only the person-machine interface and the acquisition of timely, appropriate information, but also interpersonal skills including leadership, effective team formation and maintenance, problem-solving, decision-making, and maintaining situational awareness" which coincides with and extends on John K. Lauber's original (1984) definition of "the application of human factors in the aviation system. (p. 20)

At the NASA-led *Resource Management on the Flight Deck Workshop* in 1980, the CRM concept was founded after an investigation of the Tenerife airport disaster in 1977, advised that human factor training should be compulsory for all aviation personnel (White & Lauber, 1980). It was concluded that the disaster between the KLM and Pan Am aircraft, claiming 583 lives, was due to poor ATC-pilot communication and a steep authority-gradient in the KLM cockpit (CIAIAC, 1977).

The first CRM program, implemented by United Airlines in 1981, was the first of an eventual five generations (Helmreich, 1999). After an assessment was made at the second NASA workshop for the industry that

With large demand, militaries worldwide are adopting Unmanned Aerial Systems (UAS). The pilot selection approaches outlined by Damos is required to remain dynamic, as the description of a modern pilot changes, and a steep demand for UAS operators alter how selection and training will be conducted. Services will be forced to rethink their approach to employing people with an appropriate base-level NTS skillset

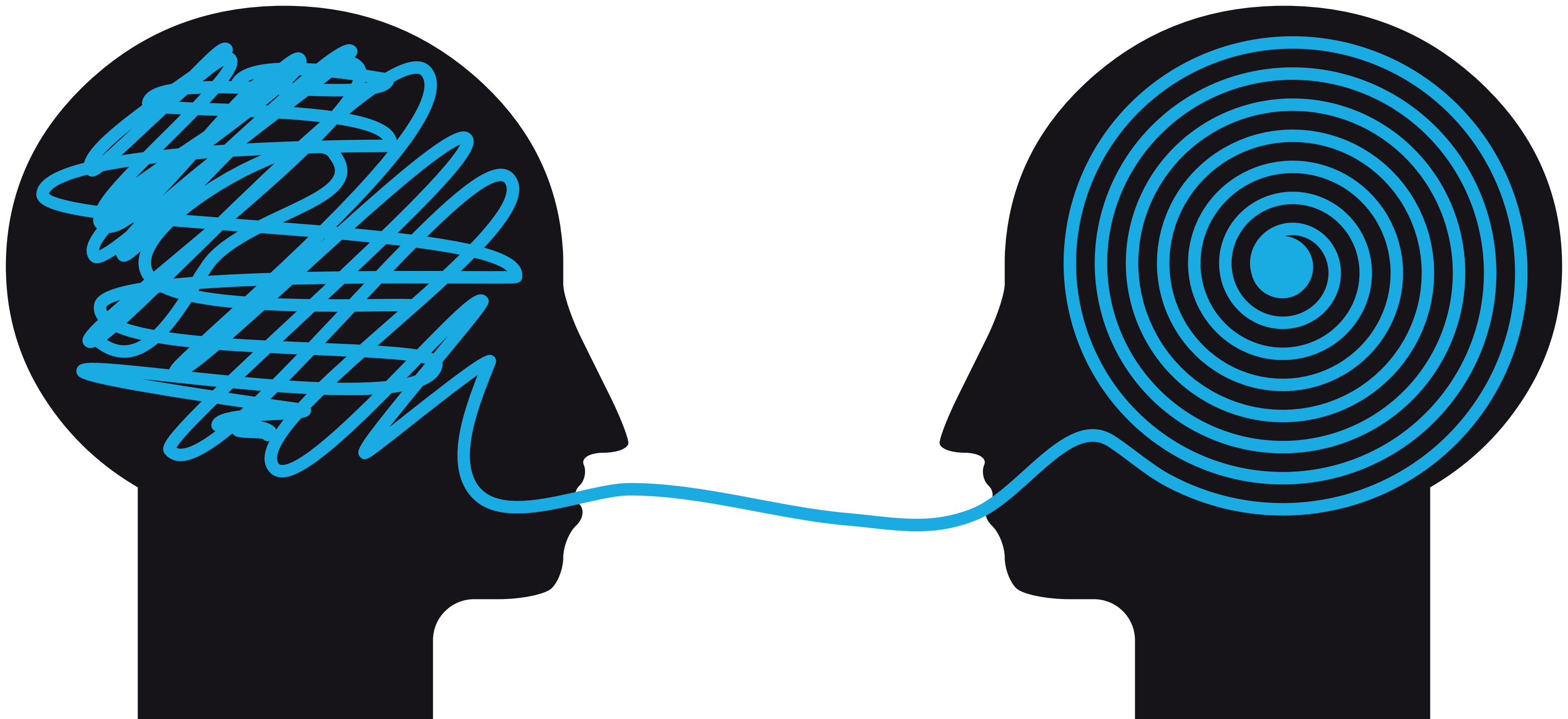
crews lacked recurrent training of CRM, a second generation of the CRM was implemented by Delta Airlines (Byrnes & Black, 1993). This new modular and team-oriented version of training addressed specific aviation concepts related to flight operations (Helmreich, 1999). The third and fourth generations focused on expanding the context of CRM, and implementing procedure into how airlines award qualifications of CRM training.

The curriculum was extended to encompass skills that pilots could use to analyse the organisational culture, and make assessments on human-factor issues. CRM should exist as an error countermeasure with three lines of defence. The first being avoidance of error, the second being stopping incipient errors taking effect, and the third being mitigating subsequent consequences of an error that has occurred.

Outlined in the Civil Aviation Authority (UK) *Crew Resource Management (CRM) Training: Guidance for Flight Crew, CRM Instructors (CRMIS) and CRM Instructor-Examiners (CRMIES)* (2006) is the CRM requirements for modern-day crew in the aviation industry. It makes two notable points, being that; CRM training for flight deck crew is mandatory based on the operator's syllabus and, that it is a requirement that recurrent training is undertaken at a minimum of once every three years. However, it is not essential to re-cover the entire syllabus in this period.

Threat-and-error-management (TEM) training was implemented by the Civil Aviation Safety Authority (Australia) from 2009 in response to International Civil Aviation Organisation's (ICAO) lead in TEM training (ATSB, 2009). In the executive summary of an ATSB report on the attitude towards TEM training, it states that "since both threats and error carry the potential to generate undesired aircraft states, the teaching of non-technical or CRM skills, along with expected behaviour policies within airlines that include them, have somewhat successfully addressed the intent of TEM over the past decade –in particular error management" (p.2).

Salas, Burke, Bowers, and Wilson, (2006) explain that the increasing universality of CRM training has led to its incorporation into other areas, including, oil and railroad industries, general transportation and healthcare. Parallels have been made between intensive care units (ICU) and the aviation industry, despite the apparent procedural differences.



ICUs consist of teams that are responsible for shorter lengths of stay, high quality of care and a lower nursing turnover. CRM aims at improving cognitive and inter-personnel skills, which are critical to ICU performance. The idea of CRM and its focus on threat and error identification as well as early countering of human mistakes, fits the criteria that intensive care unit training programs require (Haerkens, 2012).

LOSA: history, application and current status

Line Operations Safety Audits (LOSA) was developed as means of measuring and reporting on the effectiveness of CRM training and the NTS exhibited in an organisation (Harris, 2011). The Federal Aviation Administration (FAA) defines LOSA as a "proactive measure used to improve safety and enhance performance through peer observation in a non-jeopardy environment" (FAA, 2014, p.1). (LOSA) were introduced to commercial aviation in the late 1990s as a result of poor observed safety during day-to-day operations, subsequently putting flight crew at risk.

The audit process screens for both latent and overt lapse of NTS skills by trained observers (Harris, 2011). Klinect (2006) justifies that the implementation of LOSA was caused by over-reliance on reactive measures, which justified the success of safety practises in the absence of accidents.

Both the Harris and Klinect observed that the organisational safety climates are susceptive to normalisation of deviance. LOSA implementation was at the request of Delta airlines in 1994, during which time the company were developing a new CRM course (Klinect, 2006). In collaboration with Continental Airlines in 1996, the first LOSA was undertaken, which measured TEM and NTS proficiency. As a result, an error-management training course was implemented for every pilot at the airline (Klinect, 2006).

LOSA is currently utilised throughout a number of organisations. The US Air Force is introducing LOSA throughout Air Mobility Command (AMC) and the Mobility Air Force Fleet (MAF) on a four to five year rotational basis (Picha, 2015). Additionally, the concept of LOSA has been adapted to Air Dispatch, namely, Dispatch-Line Operation Safety Audit (DOSA).

The results of a recent DOSA survey at Iran Air identified underlying safety breaches that occurred, and gave the airline a number of recommendations to improve the conduct and safety of their operations (Khoshkhoo, 2018).

Adaptability and universality of CRM and LOSA

CRM and LOSA's greatest strength is its adaptability at the organisational level. Implementation of CRM-related NTS training in healthcare and LOSA influenced rollouts in air dispatch, are just two examples that show on the organisational front, that the current state of NTS training has major strengths. Additional research has been done on how CRM training is conceptualised and evaluated for introduction into air traffic control, nuclear power, maritime and gas industries (Havinga, 2017).

It's widely accepted in the aviation industry that pilot candidates in multi-crew airline operations require base-level competency in leadership, co-operation and communication (Hoermann & Goerke, 2014).

Employing the correct type of personnel that have the aptitude to fully grasp the concept of ideas surrounding safety culture and cockpit soft skills, will pave the way for CRM training to take full effect in mitigating human error. Thus, finding the correct type of applicant would act as a CRM training effectiveness multiplier.

Three differing, widely accepted approaches are taken when assessing these soft skills for pilot selection: interviews, questionnaires on personality traits and behavioural-based assessments (Damos, 2014). With large demand, militaries worldwide are adopting Unmanned Aerial Systems (UAS). The pilot-selection approaches outlined by Damos is required to remain dynamic, as the description of a modern pilot changes, and a steep demand for UAS operators alter how selection and training will be conducted. Services will be forced to rethink their approach to employing people with an appropriate base-level NTS skillset (Wiener, 2011).

Limitations: technology and individual tailoring

Limitations are inevitable when implementing a program, or in the case of NTS training, within an organisational population. The argument can be made that CRM is not tailored for every individual and as such, potential risks arise. If CRM does not remain dynamic in nature, it risks becoming obsolete (Wiener, 2010).

This extends responsibility to the evaluation cycle in a program's evolution process. For example, when considering evaluation, the lack of a systematic approach to assessing CRM training will make apparent the difficulties by ensuring crew receive consistent, and adequate NTS training (Salas, et al., 2001).

Since 1980, the onus has been on organisations to develop and deliver their own CRM training as per the policy of their respective aviation authority. Conducted studies show that CRM training has not been equally effective among all candidates for a number of reasons (Helmreich et al, 1999; Helmreich & Wilhelm, 1991). As found by Helmreich & Wilhelm (1991) personality and character traits were the factors pinpointed and the reason for ineffective CRM training outcomes. The reports suggested that a more universal package was needed within CRM training courses. Hoermann and Goerke (2014), through critical analysis, concluded that vague attitudes existed towards NTS training. Furthermore, research of CRM limitations made the conclusion that there are several important reasons to include measures of social competence in addition to cognitive tests in employee selection.

The future of CRM training: UAS

As mentioned previously, "human error is ubiquitous and inevitable" (Helmreich, 1999, p.27). The future of CRM will undoubtedly see it become implemented in other industries and domains. As research on CRM progresses, the issues with technological adaptability will need continual addressing.

Future technologies will create new hurdles for CRM research, notably: UAS, automation and small jets (Harris, 2011). Wiener (2010) explains the two problems that arise as a result of UAS. Firstly, a loss of sensory cues will restrict, if not cease, visual information, and vestibular inputs and sound.

Secondly, degrees of flight control-automation will increase, and with it, new error-management procedures for automation failure. Similarly, the implementation of small jets (that are potentially single pilot) as common transport in the future will immensely increase the cultural diversity and number of people requiring NTS training.

In CRM's case, future challenges echo the past, and the adaptability issue is something that always has, and will need addressing (Harris, 2011; Reason: Helmreich, 1999). Helmeich (2010), explains that into the future, research and evaluation should proceed in tandem with the implementation of new CRM methods, and that in a globalised modern world, exchange of information will foster a rapid evolution of NTS training.

Conclusion

CRM, LOSA, or any other form of NTS training or evaluation, will never be the answer to eliminating human performance error in any safety domain. CRM doesn't exist without limitations; however, with correct mitigation of potential training shortfalls, CRMs ability to be adaptable allows it to influence and shape how other industries approach NTS training. When NTS training results are evaluated by an effective LOSA program, a dynamic safety evolution process can mitigate human error and contribute to safe and efficient task performance.

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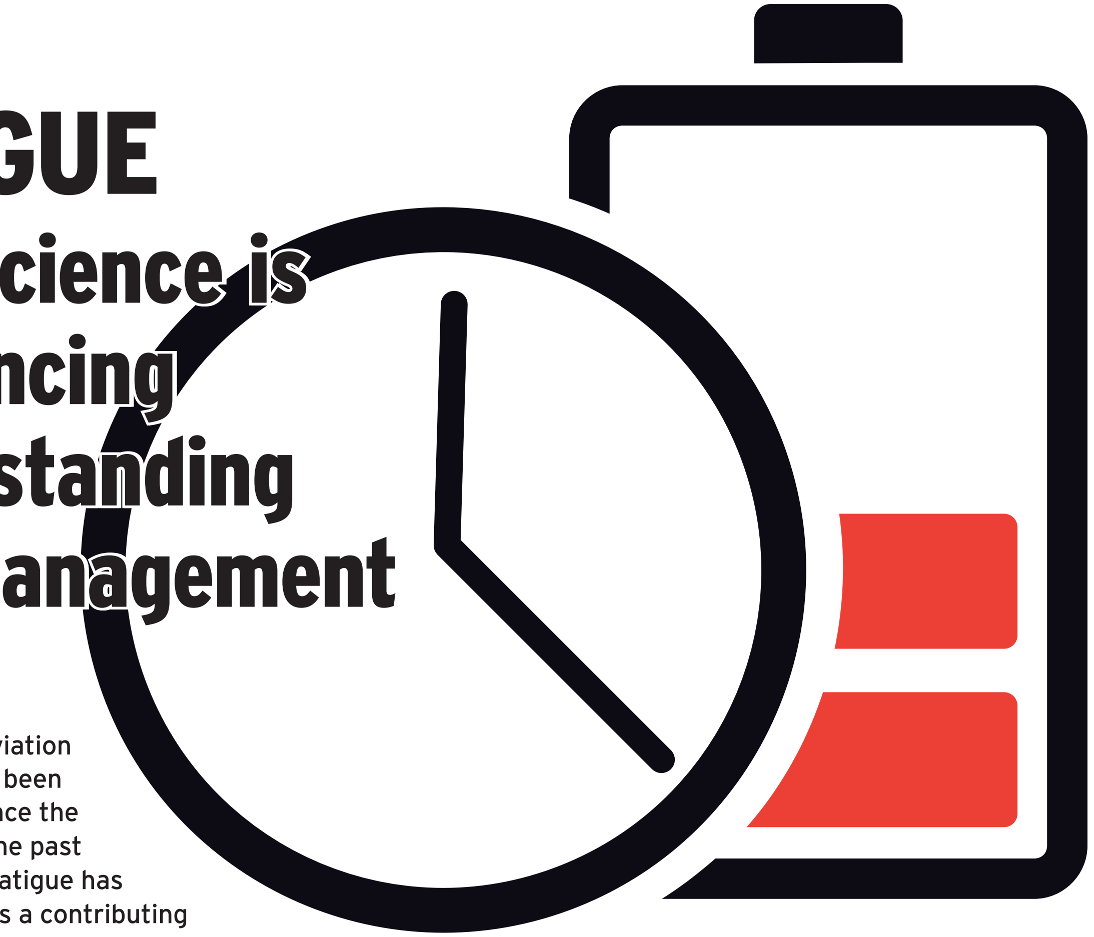

FATIGUE

How science is influencing understanding and management

By C Baker-Smith

Though the aviation industry has been operating since the 1914, it is only in the past half century that fatigue has been recognised as a contributing factor to many accidents and incidents. The issue of insufficient sleep has become significant and yet a common issue as the introduction of modern aviation operations, both in civilian and military environments has resulted in pilots experiencing unpredictable and long work periods that cause a disruption to their circadian rhythm. Previously the full effects of fatigue have not been appreciated until recent events and studies have called for changes to fatigue countermeasures employed by the industry.

An Australian master practitioner in fatigue management was quoted stating, "we have done all the research needed to properly manage the risks of fatigue in aviation." Recent studies have resulted in the development of many fatigue-management models to reduce risk.

This paper counters this statement by presenting the issues that are associated with the previous fatigue management and how recent studies have been utilised in developing strategies to overcome these issues. Furthermore, it will outline the limitations of these strategies that must be addressed in order to provide current and relevant fatigue risk management systems that are effectively applied in the modern aviation industry.

Previous crew rest and duty guidelines:

In the US crew rest in the commercial aviation realm is stipulated by the Federal Aviation Administration (FAA) in the Code of Federal Regulations (CFRs). In this code, flight crews, both augmented and non-augmented, are entitled to a 10-hour rest period prior to duty with non-augmented requiring an additional 10-hour rest period after duty. There are also restrictions to control the maximum flight and duty time over extended periods of time including a week, month and year which are not to exceed 30, 100 and 1400 hours respectively (Caldwell et al. 2009).

When compared to Australian flight time limitations as stipulated in Civil Aviation Order section 48.1 (2004), a crew member's flight hours are not to exceed 900 in a year. Since there is such a large difference between Australia and the US it can be implied that these values are arbitrarily determined and are not based on human physiology.

As the complexity of the aviation industry develops, these flight and duty time limitation frameworks (FTL) have been rendered ineffective in managing personnel in an environment that operates continuously. The values in these prescriptive frameworks were one of the first forms of fatigue management; however, due to their restrictive make up they do not take into account recent developments in work policies, technology and research (Caldwell et al. 2003).

It is important that the full effects of circadian disturbances to sleep quality by transition through time zones is appreciated and applied to risk mitigation strategies. Throughout *Fatigue Countermeasures* research paper (Caldwell et al. 2009), it was identified that both long-and short-haul pilots associated their fatigue to time pressures of unpredicted duty schedules over consecutive days and the inability to fully recover due to insufficient rest periods. Furthermore, a study was conducted by McGown and Wright (2001) to assess the effectiveness of FTL as a fatigue-management strategy for civil long-haul operations. Their findings uncovered that pilots experience an unacceptable fatigue during lengthy flights, especially at night.

During the study they found that in many cases this fatigue led to episodes of micro-sleep that were greater than 20 seconds and thus impaired a pilot's performance due to disorientation when recovering from entering deep sleep (McGown & Wright, 2001).

Fatigue-Risk-Management Systems

Each operation in the aviation industry has its own value of risk that consists of a variety of physiological factors including but not limited to: extended duty hours, sleeping or working during opposing circadian times and transitioning between multiple time zones (IATA, ICAO, IFALPA, 2015). These factors, coupled with specific company or airport conditions require a model to address their combined risk on an individual basis.

A fatigue-risk-management system (FRMS) uses a scientific foundation to address physiological and operational factors to optimise safety and performance levels of an individual flight operation. FRMS can be developed to be a standalone system or can be utilised as part of a safety management system (SMS), as employed by CASA (2017). The role of FRMS is to apply multiple strategies to manage multiple sources of fatigue. As opposed to the binary approach of the FTL, an operation is either inside the limits or not – FRMS offers flexibility and takes into account the differences of both operations and crew members (Caldwell et al. 2009).

The concept of FRMS was developed based on scientific evidence that indicated fatigue could be caused by multiple factors, especially in a 24/7 environment. It is now acknowledged that adequate sleep is required for recovery – not just rest. Also, that a daily cycle known as the circadian rhythm greatly affects human performance, especially when disturbed by transitions through time zones. These factors, in conjunction with the early understandings of time-on-task fatigue have resulted in a greater appreciation of human error (IATA, ICAO, IFALPA, 2011).

FRMS is a relatively new concept in the realm of fatigue management. New Zealand Civil Aviation Authority Regulations were the first to apply principles of FRMS to their FLT (Caldwell et al. 2003). ICAO, in conjunction with IATA and IFALPA released their first edition in July 2011 and a second in 2015. As stated in the disclaimer, their FRMS is under an on-going review as more information about fatigue and fatigue management is unearthed and regulations are adapted (IATA, ICAO, IFALPA, 2015). Through this disclaimer these organisations recognise the importance of current research to develop the most applicable management system.

Within the ICAO FRMS, fatigue is described as a state of imbalance between the waking activity exertion, both mental and physical and recovery from such exertion, in the form of sleep. Thus, based on this approach a reduction in exertion or the improvement of sleep is required to diminish fatigue (IATA, ICAO, IFALPA, 2015). There are two concepts central to achieving this. Firstly, sleep science which investigates the effects the sleep cycle, sleep quality in different environments and sleep recovery. Secondly, how circadian rhythms influence the quality of performance and sleep. The research in these areas has been used to develop risk-mitigation strategies (IATA, ICAO, IFALPA 2011; Harrison, 2011).

These strategies are then used in a six-step risk-management process. The fatigue risk management process is designed to be adaptable if mitigation strategies do not effectively reduce the hazard (CASA, 2017). The process uses data analysis of potential fatigue hazards and safety risk assessments of identified hazards before applying an appropriate mitigation strategy. The final action of the process is monitoring the efficiency of the mitigation strategy, if the strategy is not effective then the process is reapplied at the appropriate stage (IATA, ICAO, IFALPA, 2015; CASA 2017).

Biomathematical models

Biomathematical models manage fatigue by using research to develop predictive formulas that are based on individual factors of the flight-crew member including sleep history and circadian rhythm and also the operation's requirements. These models utilise the latest technological and research advances in fatigue management and can be applied to the broad spectrum of operations that make up the modern aviation industry (Harris, 2011; Caldwell et al. 2003).

A guidance document released by CASA (2014) on biomathematical fatigue modelling evaluates the integration of such models to be part of flight crew FRMS. This guidance document listed seven models for consideration based on availability of peer review research papers, presented as a usable computer-based function and its applicability to the aviation industry. The models considered were: the Boeing Alertness Model (BAM), the Circadian Alertness Simulator (CAS), the Fatigue Assessment Tool by InterDynamics (FAID), the Fatigue Risk Index (FRI), the System for Aircrew Fatigue Evaluation (SAFE), the Sleep, Activity and Task Effectiveness Model and associated Fatigue Avoidance Scheduling Tool (SAFTE-FAST) and the Sleep Wake Predictor (SWP) (CASA, 2014).

CAS, FAID and SAFTE-FAST are models that use the foundations of the original sleep regulation model developed by Alexander Borbély in 1982 and then adapted to incorporate modern research (CASA, 2014). Borbély's model employed homeostatic pressure and circadian rhythm to justify timings and durations of sleep. BAM, SAFE and SWP are all progressions of Åkerstedt and Folkard's Three-Process Model of Alertness, which in its self was an extension of Borbély's model (CASA, 2014).

It is regarded as a three-process model since it includes the effects of sleep inertia, the temporary diminishing of performance immediately felt after awakening. With the exception of FRI, the contemporary models also incorporate a task-related aspect to allow their application to a large variety of tasks (CASA, 2014; Caldwell et al. 2009).

FRI uses three separate components to compare work schedules and examine potential risks associated with changes to these schedules. The components of this model are: analysis of behaviour pattern and environmental factors prior to duty; effects of duty requirements, including time of day and length; and finally, the activities and rest scheduled for the shift (CASA, 2014).

Biomathematical models have only recently been introduced to civil aviation. Many of these models have limitations in application since population averages are used for predictions and thus, cannot predict risk using an individual's immediate fatigue levels or partial physiological fatigue factors (CASA, 2017). These models; however, are juvenile and as stated in many research-paper discussions require the incorporation of subtle cumulative factors of fatigue (Belyavin & Spencer, 2004).

Conclusion

The purpose of this essay was to present a counter argument to the Australian master practitioner in fatigue management and demonstrate the impact research has had on fatigue management. This paper has outlined the significant changes that have been made to risk management in recent years. Risk management is currently in the process of transitioning from prescriptive schedules to performance-based regulatory frameworks in order to adequately manage fatigue despite the high demands of the modern aviation industry. The reason for this shift is to allow operators to tailor their operations in order to provide optimal crew management systems.

As the aviation industry has expanded into continuous operations, previous prescriptive management methods have been proved to be ineffective in managing risk as they lack the application of scientific research. The scientific concepts of sleep and circadian rhythms that underpin FRMS, are the result of decades of research and studies as well as its integration to risk management processes. FRMS have only recently become the core component of many civil aviation fatigue risk management systems and are based on modern research relating to circadian rhythms and sleep science.

Through this new approach to fatigue management, it is clear that there is a constant demand for new discoveries relating to fatigue. Biomathematical models are another way of proving the inaccuracy of the statement by the Australian master practitioner in fatigue management since as these models are developed based on continual scientific findings.

Lastly, aviation is an industry that is heavily dependant on technology. Therefore, since technology is constantly evolving to become higher performing and potentially more automated capability, the requirements of aircrew will be constantly varying to support these developments. Thus, it is imperative that continuous studies be held to ensure fatigue is properly mitigated to reduce human error.

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Technology and the decline of cockpit proficiency

By Lauren Finnerty

The introduction of new technologies in the aviation industry has seen a drastic improvement to safety and efficiency but it also introduces new challenges (Funk et al., 1999).

The changing flight deck has changed the way pilots fly; automation and integrated technology in the cockpit has resulted in less manual flying by pilots and increased software monitoring (Moriarty, 2015b). This has resulted in a decline in the manual flying skills of modern pilots, a concerning phenomenon that grows as the industry continues to adopt technology to increasingly complex operations (Childs & Spears, 1986; Ebbatson, Harris, Huddlestone, & Sears, 2010; Funk et al., 1999; Hanusch, 2017; Haslbeck & Hoermann, 2016; Pope, 2016).

This essay will investigate this phenomenon from a human-factors perspective by firstly exploring the modern flight deck. Then, potential human factors at play will be identified and ways to mitigate their impacts will be discussed.

Finally, this issue is borne from exponential innovation within the aviation industry; an occurrence likely to continue well into the future. Therefore, the challenges for the next generation of pilots will also be considered.

Cockpits are becoming more advanced and in being so, make it increasingly difficult for pilots to maintain manual flying skills.

Interestingly, Pope (2016) observes the increase in integrated technology in the cockpit and explains that despite it raising the complexity of the workspace it has in fact made his profession as a pilot much easier. Evidently this raises the concern that "[pilots] are becoming so adept at using and managing all the technology at our disposal that our basic airmanship skills can degrade, often without us realizing to what degree" (Pope, 2016).

This is translating into serious safety concerns as Haslbeck and Hoermann (2016) state that in 26 per cent of commercial aviation accidents analysed by the International Air Transport Association between 2010 and 2014, there was "tangible evidence that manual-flying flight-crew errors were involved". Safety is critical in the aviation space; even the slightest incursions beyond the safe operating envelope can have disastrous effects for passengers and the wider industry (Stolzer et al., 2011). The decline in manual-flying skills of modern pilots is a concern of the entire aviation industry; pilots, operators, regulators, manufacturers and researchers alike (Ebbatson et al., 2010). However, the conditions in which this issue is born are effectively explored through the application of human-factors research.

Human factors in aviation

"The physical hazards of aviation are well known, but since the dawn of manned flight, human factors have constituted the greatest areas of risk." – Group Captain Rob Lee (Murphy, 2005)

Humans are integral to the aviation systems. We bring to the system inherent advantages and risks. Understanding how humans perform and interact with systems allows for the designing and mitigation for these benefits or risks and has proven effective given the improved safety and efficiency the industry has seen over the past decades (Moriarty, 2015b).

The more we know about human performance the more effective our efforts to facilitate an 'optimal relationship between humans and the demands and characteristics of the workplace'; however, as Murphy (2005) states; because all humans have different and inconsistent performance capabilities, and because workplaces are constantly changing, this is a complex task". The modern aviation industry is an example of this complexity; the modern cockpit has both improved pilot performance yet also introduces new inherently human challenges.

The advanced cockpit: modern challenges for modern pilots

Only decades ago flying an aircraft was an intensively physical and sensory orientated task (Mosier, 2010). Innovative feats of engineering saw the controls and systems of first and second generation aircraft improve safety through efficiency and the 1980s saw the beginning of the era of automation (Hanusch, 2017). Funk et,al (1999) defines automation to include "flight directors, autopilots, auto throttles, flight management systems, and centralized warning and alerting systems". The introduction of automation and glass cockpits saw the saw the increase in safety, economy and reliability, reduction in crew workload, more precise control and navigation, display flexibility and economy of the flight deck space (Harris, 2003). Additionally, modern cockpits utilise other integrated technology in the cockpit – iPad replacing flight plans for example.

This advanced workplace has introduced modern challenges for pilots. Automation has given the industry the ability to conduct more flights over longer routes, in tightly controlled airspaces and aerodromes.

However, this results in longer shifts for aircrew and more complex situations for pilots, which introduces further factors of fatigue, stress and complacency. The apparent paradox of being exposed to these three factors, potentially all in the same flight, is the inherent environment for modern pilots. The issue of manual flying skills among modern pilots is borne of this environment.

Manual Flight Skill Decline: Potential Causes

Recent studies attribute the decline in manual flying skills among pilots to automation ("CAA PAPER 2004/10 – Flight Crew Reliance on Automation," 2004; Childs & Spears, 1986; Funk et al., 1999; Hanusch, 2017; Harris, 2003; Haslbeck & Hoermann, 2016; Moriarty, 2015a). Automation has advanced to the current point where its reliability is almost perfect, and instances of unexpected automation activity are decreasing as we continue to improve the systems (Harris, 2011). Reliability means aircraft are now designed to be flown almost entirely with automation, leaving the pilot to monitor; ensuring the system doesn't surprise him

(Hanusch, 2017). Skill fade or skill decay is the term coined to the decline of manual flying skills due to lack of use or practice. The prevalent use of automation in modern flying operations has resulted in limited instances or opportunities for pilots to exercise their manual flying of the aircraft (Harris, 2011). Although pilots are required to demonstrate their abilities in order to maintain licencing proficiencies, this testing is generally required twice a year and this time frame has been proven to be sufficient for skill decay to have effect on manual flying abilities (Childs & Spears, 1986; Haslbeck & Hoermann, 2016; Moriarty, 2015a).

Disengaging the system for manual operation introduces levels of risk to operations now seen as unacceptable, therefore it is generally not permitted (Hanusch, 2017). Moriarty (2015a) raises that: *"If we are to be software managers, we cannot be criticized when we are called on to use our "skills" only to find them degraded by lack of use. If we are to be pilots in the old-fashioned sense of the word, we need to decide when, how and under what conditions we should be allowed to practice our skills, and the industry has to accept that this, in itself, introduces a risk into the system."*

Disuse of manual skills is not the only implication automation has introduced; reliance on automation components can lead to complacency. According to Civil Aviation Authority Paper 2004/10 – *Flight Crew Reliance on Automation* (2004) "Pilots may become complacent in highly reliable automated environments where the role has become supervisory and lacks practice in direct control". Complacent pilots disengage from the flying operation and if circumstances arise where it is necessary to take manual control of the aircraft they will take longer to react due to lack of situational awareness (Moriarty, 2015a). Even the skills of monitoring are susceptible to lack of use;

"information from instrument scans and out-the-window scenes is important, monitoring requires a proper sense of timing of actions which, in turn, requires a clear cognitive pattern of how the components of an action relate to each other. Such cognitive patterns can be disrupted significantly over time if they are not practiced and reinforced regularly." (Childs & Spears, 1986)

Complacency leads to poor monitoring and according to Moriarty (2015a), humans are already inherently terrible at it. Poor monitoring could result in poorly judged response in a catastrophic situation due to unawareness of the systems operation (Moriarty, 2015a). Additionally, complacent pilots tend to develop an over-reliance or automation bias and incorporate it in operation where manual flying should be sufficient (CAA PAPER 2004/10 – Flight Crew Reliance on Automation, 2004). This risks creating a heavier pilot workload and increases opportunity for error and, perhaps even more concerning, can conceal poor manual flying skills (Hanusch, 2017).

Complacency and automation bias have a dangerous relationship with practical drift; the slow separation of actual operation and stipulated procedure (Laurence & Murphy, 2005). Cockpits are hierarchical workplaces; complacency can spread through the development of habits which can lead to organisationa-wide separation from accepted practice (Hanusch, 2017). Over time, pilot vigilance for complacent monitoring or bias for reliable automated systems could experience drift, potentially resulting in fatal consequences if pilots aren't prepared to manually fly an aircraft in an emergency (von Thaden, Wiegmann, & Shappell, 2006).

The increased risk of complacency and automation bias can be explored by investigating the design of modern cockpits. Pilots often need to switch between focused and divided attention throughout flight operation, information display determines the effectiveness of achieving this (Harrison & Vicente, 1995). Glass cockpits have replaced instrument dials with multi-function electronic displays, but as Moiser (2010) points out they show "data rather than cues". Harrison and Vicente (1995) articulate that "opaque overlapping window designs are problematic for divided attention (some information cannot be seen) but facilitate focused attention (the hidden background window cannot create visual interference)." Pilots need to be able to switch between these states of attention and often fail to recognise the need for this to occur without cues from cockpit displays.

It is important that this human factor is considered in the design of cockpits as we are still the centre of the aircraft control system. Integrated technology has introduced new distractions to the cockpit. Although allowing precise information display, things like iPad flight planners can further divide attention and result in a loss of situational awareness. As soon as a pilot loses situation awareness he is in danger of poor decision making and errors if the requirement to take manual control of the aircraft arises.

The only way to address these causes is through training and maintenance of a generative safety culture. To combat skill decay, frequent practice during normal operation or in the simulator is required (Moriarty, 2015a). Training and practice will also aid management of complacency and automation bias; however, the maintenance of a safety culture will also decrease the prevalence of these issues in the cockpit.

An organisation with a generative safety culture, a culture fostered by an organisational commitment to safety, will address concerns of declining manual skills by providing this training and practices for pilots (Stolzer et al., 2011). It encourages pilots to remain vigilant and will alleviate automation bias as pilots are confident in their skills and not afraid of punitive action for slight flight plan deviations (Hanusch, 2017). These preventative measures are essential to ensure pilots are proficient at manual flying and therefore ensuring the safety of the aircraft.

Challenges for future pilots

"This generation is seeing the key nature of control has changed from the stick-and-rudder skills of an onboard pilot. The operator is now more likely to interface with the aircraft using something akin to a conventional computer interface." (Harris, 2003)

Pilots have already adapted incredibly to the current advancements in technology experienced by the industry. If history is any indication, this rapid adaption will need to continue in order to maximise capability. However, studying human factors has shown that some things should never change; complete safety is only possible when the human factor is considered (Moriarty, 2015b). It is vital that future pilots continue to maintain safety systems accounting for humans in the industry and more so as the environments continue to advance and develop (Stolzer et al., 2011). Without this systematic approach the diagnosed decline of manual flying skills could have continued on unnoticed, unresearched and dangerous.

Harris (2003) conveys that the modern pilot is already removed from the traditional "stick-and-rudder" operator. Pilots already require significant cognitive ability to operate the aircraft, the question is now raised as to when will they not require physical manual control skills at all? Humans are still the centre and authoritative controllers of the aviation system and will never be entirely removed (Hanusch, 2017). Yet to disregard consideration as to if or when these skills will ever be obsolete would be foolish. Noting the incredible advancements in aviation in less than a century, to believe that this will always be the way aircraft operate is simply unrealistic.

Conclusion

The decline of manual flying skills in modern pilots is an issue rooted with the study of human factors. Errors in manual pilot flying attributed to 26 per cent of accidents between 2010 and 2014 suggesting this is a serious issue impacting upon the essential safety of the aviation industry (Haslbeck & Hoermann, 2016). The increase in automation has improved efficiency, safety and economy; however, restricts opportunities for pilots to practice manual flying skills. This disuse has led to skill decay of manual-flying skills in modern pilots.

Automation has also introduced the challenge of ensuring human performance when the systems are so reliable. Complacency and automation bias are additional factors that potentially contribute to this issue, both cause a reduction in situational awareness and increase reaction time and opportunity for pilot error when manual flying is required. Frequent training and practice and the maintenance of a generative safety culture can combat this deficiency. Evidently this issue currently needs to be addressed; however, it does raise interesting considerations for future pilots. At the current rate of advancement, will there ever become a point where ensuring manual flying skill proficiency will be unnecessary for future pilots?

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Aviation maintenance errors

Combating human nature in the pursuit of safety

By Travis Adkins

"Over two thousand years ago, Roman orator Cicero cautioned that it is the nature of every man to err". Throughout the development of society as we know it, this idea has been continued as it is widely accepted among psychologists and philosophers that errors in both human knowledge and conduct are inevitable (O'Donohue & Ferguson, 2003).

Therefore, it is easy to understand why according to Harris (2011, p. 5) "human error is now the primary risk to flight safety with up to 75 per cent of all aircraft accidents now containing a major human-factors component." Clearly, these findings highlight the requirement for human factors to be considered in all aspects of aviation in order to improve the safety of the industry. One critical aspect of the industry is aviation maintenance, where findings concluded that "aviation maintenance errors account for between 12 and 15 per cent of the global aviation accidents initiators, which rises to 23 per cent when serious incidents are included" (Rashid, Place & Braithwaite, 2012, p. 171). This paper will argue that the integration of human-factors research and interventions into the aviation maintenance domain have improved the safety of aviation. This will be achieved through an analysis of three subjects: human error and risk controls, organisational influences and risk management.

Context

Before discussing how human-factors research and interventions have impacted aviation maintenance, it is important to define a number of key terms that will be frequently used throughout the paper. Human factors is defined as the "multidisciplinary field devoted to optimising human performance and reducing human error" (Federal Aviation Administration, 2004, p. 2). Found predominantly in socio-technical systems, human factors incorporates elements such human physiology, psychology, ergonomics, engineering, medicine and many more. Now that human factors has been defined, a background on aviation maintenance must be established. Aviation maintenance is defined by the European Aviation Safety Agency (EASA) as "any one or combination of overhaul, repair, inspection, replacement, modification or defect rectification of an aircraft or aircraft component" (European Aviation Safety Agency, 2013, p. 72).

The nature of aviation maintenance results in personnel being subjected to hazardous conditions that are amplified by the mental and psychological pressures that accompany each task (Rashid et al, 2012). These pressures derive from personnel understanding the cost of maintenance errors, which could potentially result in fatal incidents. One clear example is Nigeria Airways Flight 2120 which crashed in 1991 killing 261 people after experiencing an inflight fire (Ranter, 2018).

Subsequent investigations into the crash revealed that before the aircraft was dispatched, aircraft technicians identified a major defect; however, they failed to rectify it (Ranter 2018). This example highlights the extreme cost of maintenance errors and the essential role aviation maintenance plays in aviation safety. Furthermore, aircraft accidents such as the aforementioned reinforce the requirement of human-factors research and interventions into aviation maintenance in order to improve the safety of aviation.

Human error and risk controls

Consequently, there has been significant research conducted by a number of organisations and individuals into identifying and analysing human error within aviation

Error categories of HFACS-ME framework

	FIRST ORDER	SECOND ORDER	THIRD ORDER
Level 1 (latent conditions)	Management conditions	Organisational conditions	Inadequate processes Inadequate documentation Inadequate design Inadequate resources
		Supervisory conditions	Inadequate supervision Inappropriate operations Uncorrected problem Supervisory misconduct
Level 2 (latent conditions)	Maintainer conditions	Maintainer medical conditions	Maintainer mental state Maintainer physical state Maintainer limitations
		Crew co-ordination	Inadequate communication Inadequate assertiveness Inadequate adaptability/flexibility
		Maintainer readiness	Maintainer training/preparation Maintainer certification/qualification Maintainer infringement
Level 3 (latent conditions)	Working conditions	Working environment	Lighting/light Weather/exposure Environmental hazards
		Working equipment	Equipment damaged/not serviced Equipment unavailable/inappropriate Equipment data/uncertified
		Workspace	Confining workspace Obstructed workspace Inaccessible workspace
Level 4 (unsafe acts)	Maintainer acts	Errors	Attention/memory Knowledge-/rule-based Skill-/technical-based Judgement/decision making
		Violations	Routine Infraction Exceptional Flagrant

Figure 1. HFACS-ME Framework (Rashid, Place & Braithwaite, 2012, p. 178)

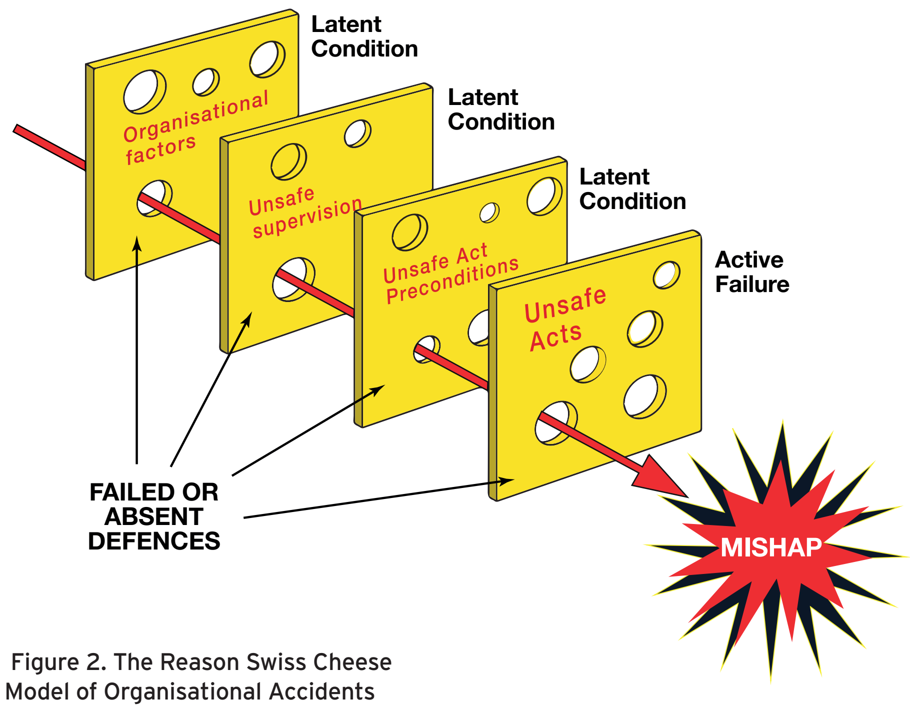

Figure 2. The Reason Swiss Cheese Model of Organisational Accidents

maintenance. "Human error is defined as the failure of planned actions to achieve their desired ends – without the intervention of some unforeseeable event" (Rashid et al, 2012, p. 171).

Undoubtedly, the aviation maintenance domain is a complex environment, therefore, it should come as no surprise that the linchpin in the industry, the human, is capable of making errors across all levels of an organisation (Gramopadhye & Drury, 2000).

Over time, this fact has been brought into sharp focus and thus, the aviation industry has worked to develop risk incident analysis tools (Chang & Wang, 2010).

Early research focused predominantly on the human and individual level factors which is evident in the SHELL model, as the liveware component is at the very center of the model (Chang & Wang, 2010). The purpose of the model is to illustrate that liveware alone, or when combined with the other components, is the source of all errors. This is indicative of the fact that human error is the common driver of aviation maintenance mishaps.

Despite this, no comprehensive human error framework existed in the aviation maintenance domain until the Human Factors Analysis and Classification – Maintenance Extension (HFACS-ME) model was developed (Weigmann & Shappell, 2001). HFACS-ME captures latent conditions, active failures and places them into four categories (Weigmann & Shappell, 2001). Located in Figure 1, it can be seen that the HFACS-ME framework is able to "capture human factors induced error causes and facilitate the recognition of absent or defective associated defences" (Rashid et al, 2012, p. 177).

To demonstrate the effectiveness of the HFACS-ME model, a case study will be presented. The US Navy selected 15 NTSB accident investigation reports and used the HFACS-ME model to determine the maintenance errors that caused the incident (Schmidt, Dawson & Figlock, n.d.). The result was that 55 unsafe acts were identified – 3.7 per case compared to the average of 2.4 identified in the original reports (Schmidt et.al, n.d.). Clearly this demonstrates the effectiveness of the model in identifying potential maintenance errors. Therefore, upon identification of absent defences, risk controls can be implemented to address errors and improve safety.

Risk controls, which fall into two categories, are a human-factors intervention aimed at reducing human error within an organisation (Hobbs, 2008). Preventative risk controls aim to deter the chance of human error occurring from the outset and include training, physical components and engineered solutions (Hobbs, 2008).

Recovery risk controls are designed to reverse the effects of a human error that has been made and include secondary checks, inspections, and procedures (Hobbs, 2008). One key criticism of risk controls is that they differ in their effectiveness, with engineered solutions being the most effective control and self-checking of work being the least effective (Hobbs, 2008). Despite the controls differing in effectiveness, well implemented controls contribute to improving the overall safety of aviation.

With this is mind, it is clear that human-error frameworks and risk analysis tools are contributions of human factors research that have improved the safety of aviation.

Organisational influences

Importantly, the aviation maintenance domain now widely accepts that maintenance errors are caused by more than just individual failures at the lowest level. "While acknowledging that maintenance personnel are responsible for their actions, it must be recognised that in many cases, the errors of maintenance technicians are the visible manifestation of problems with roots deep in the organisation" (Hobbs, 2008, p. 7). Evidence of this can be viewed in the Reason Model, is included as Figure 2. The model illustrates that the unsafe acts that result in maintenance errors are often caused because of organisational conditions (ATSB, 2007).

A common criticism of the Reason Model is that, because of its simplistic nature, it fails to provide a comprehensive guide of a maintenance error causation (ATSB, 2007). However, the model wasn't designed to perform this function and there is still an absence of a subsequent model that meets this description (ATSB, 2007).

Despite this criticism, the model identified the requirement for research to consider the organisational factors of aviation maintenance.

Perhaps the most pertinent organisational factor identified is the requirement for a positive safety culture. Safety culture is defined as "the shared and learned meanings, experiences and interpretations of work and safety...which guides people's actions towards risk, accidents and prevention" (Atak & Kingma, 2011, p. 269).

While this definition accurately defines safety culture, it is important to note that a safety culture is generated from the top tiers of an organisation which then filters through the entire workplace (Sumwalt, 2011). This is captured in the Ripple Model of safety culture, which was created by Morley and Harris (Harris, 2011).

Situated in Figure 3, the Ripple Model identifies "three threads running across people within (and without) an organisation, irrespective of their level and role" (Harris, 2011, p. 284). Concerns, actions and influences make up those three threads with the aim of demonstrating that outside elements vastly influence the safety culture in an aviation maintenance environment (Harris, 2011).

Through utilising the Ripple Model, safety cultures of aviation maintenance organisations and aviation incidents can be analysed. Analysis proves to be a proactive measure that allows for areas of concern to be identified before an incident occurs. Human-factors interventions can then be implemented within an organisation to reduce the risk of an incident, thus improving the safety of aviation.

Risk management

While identification of safety risks and hazards in aviation maintenance is crucial in improving safety, identified risks can still lead to incidents if they are not managed appropriately. Thankfully, human-factors research has revealed tools for effectively managing risk within an organisation. The first tool to be discussed is an error management system that is "based on understanding the nature and extent of error, changing the conditions that induce error, determining behaviours that prevent or mitigate error, and training personnel in their use" (Helmreich, 2000, p. 781).

A number of experts have theorised that one of the key components of error-management systems is generating an environment that can tolerate and contain errors (Reason, 2000).

Without a sufficient error-reporting system in place, aviation maintainers may cover up maintenance errors due to a strong fear of negative consequences that may follow an admission. To illustrate, a 1998 study conducted in Australia focusing on aviation maintenance engineers concluded that "over 60 per cent reported having corrected an error made by another engineer, without documenting their action, to avoid potential disciplinary action against the colleague" (Hobbs, 2008, p. 29). Evidently, there is a significant

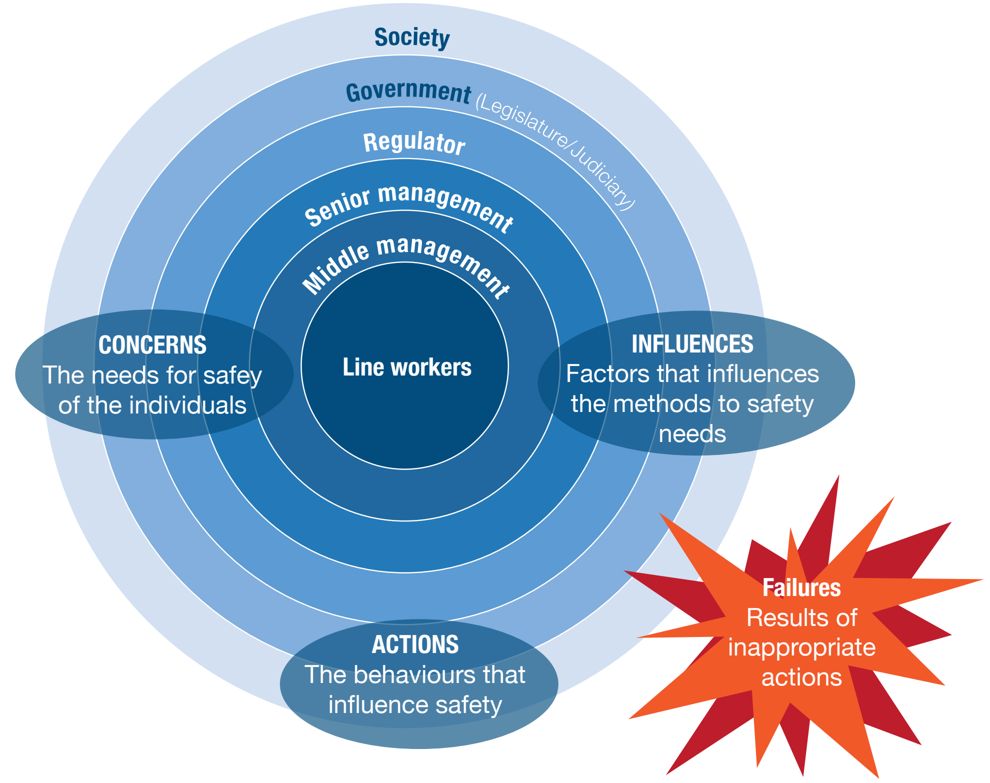

Figure 3. The Ripple Model of Safety Culture (Harris, 2011 p. 285)

problem that aviation maintenance organisations must address in order to improve the safety of aviation.

Consequently, a number of tools have been introduced to address this issue such as the Maintenance Error Decision Aid (MEDA) model. Developed by Boeing, MEDA aims to analyse contributing factors to determine the causes of maintenance errors (Latorella & Prabhu, 2000). In a field test, the model was found to be a useful investigation tool, which indicated maintenance errors (Latorella & Prabhu, 2000). Furthermore, survey data indicated "that maintenance personnel's understanding of human performance issues improved after using MEDA" (Latorella & Prabhu, 2000, p. 150). Undoubtedly, the MEDA tool is a human-factors intervention that enhances error reporting systems, error management and the safety of aviation. This is highlighted by a survey conducted with 237 aviation maintainers in which 58 per cent of respondents indicated that maintenance error would decrease due to the tool being introduced within the organisation (Rankin, Hibit, Allen & Sargent, 2000).

Additionally, another human-factors intervention that can drastically improve the safety of aviation maintenance is human-factors training. Human-factors training aims to "improve safety in aviation by making states more aware and responsive to the importance of human factors in aviation operations through the provision of practical human factors material" (International Civil Aviation Authority, 1991, p. i).

A case study which demonstrates the effectiveness of human factors training, is the two-day training course delivered to aviation maintenance workers at Continental Airlines (Edkins, 2002). The result of the course "was a 68 percent reduction in ground damage incidents" over the annual period (Edkins, 2002, p. 261).

Ultimately, error-reporting systems and human factors training are interventions that significantly reduce the risk of maintenance error. Therefore, aviation maintenance organisations should ensure they utilise the aforementioned in order to improve the overall safety of aviation.

Conclusion

Human-factors research and interventions in the aviation maintenance domain have undoubtedly increased the safety of both aviation maintenance, as well as aviation as a whole. Firstly, analysis of human error and risk controls identified that through human error frameworks such as HFACS-ME and the implementation of risk controls, maintenance error could be reduced in organisations, thereby increasing the safety of aviation. Secondly, analysis of organisational influences concluded that through analysing the safety culture of an organisation, areas of concern could be identified and addressed before an incident occurs.

Lastly, analysis of risk management illustrated that error reporting systems and human factors training are two effective methods in reducing maintenance error. In conclusion, combining the human-factors interventions identified in this paper with further future research of human factors, the aviation industry will be well equipped with the tools necessary to deal with future challenges while simultaneously improving the safety of aviation.

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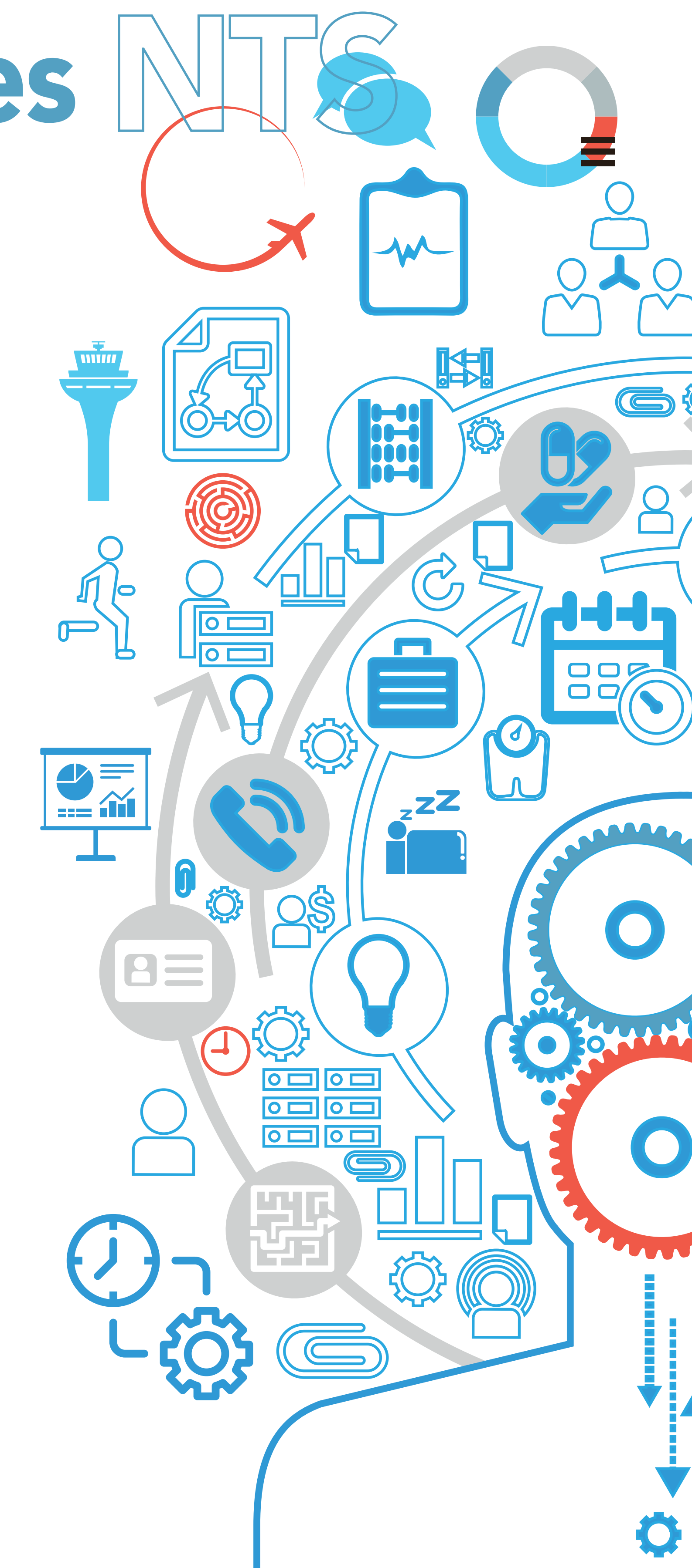
Aviation non-technical skills courses



DASM AL8 introduced a new training framework to replace the CRM and MHF programs

Key changes include:

A change in terminology from Crew Resourse Management (CRM) or Maintainence Human Factors (MHF) to **NON-TECHINICAL SKILLS (NTS)**. The term NTS denotes targeted human-factors training designed to promote reliable and effective performance. It promotes the integration of technical and non-technical training and assessment and recognises that not all Defence aviation personnel work in crew-based environments.

Aviation NTS Trainer Course replaces SFAC and prepares participants to deliver NTS Foundation and Continuation and awareness training.

Aviation NTS Foundation Course replaces CRM and MHF Foundation courses and will be integrated into all initial employment training for aviation-related trades.

Aviation Continuation Training replaces refresher training sessions and consists of targeted scenario-based NTS training packages developed by DFSB. It must be conducted every two years for all aircrew, JBAC, ABM, UAS pilots and operators, engineers and maintenance personnel.

The new framework supports a move beyond classroom-based NTS training to the conduct of skills-based training integrated into the broader training system. There are several evidence-based techniques for assessing performance; DFSB recommends using the Method for Assessing Personnel Performance (MAPP) contained in the DASM.

For more information on NTS visit the DFSB intranet homepage

NON-TECHNICAL SKILLS TRAINING

and its relevance into the future?

By Sean O'Sullivan

Captain Sullenberger displayed the effectiveness of non-technical skills (NTS) in an extreme situation, when he safely landed flight 1549 in the Hudson River; he credited his crew's teamwork and communication to making it possible (Morgan, 2017) (CASA, 2016).

NTS training has been used by the aviation industry for almost 40 years, to assist in reducing the human-factors element in aviation accidents (Helmreich et al., 1999, p. 19).

This paper will discuss NTS and crew resource management (CRM) training, analyse the current status of NTS training, explain the strengths and limitations of NTS training and finally explore its future. It is crucial that NTS training continues to deliver increased safety and efficiency to the aviation industry and is ready to adapt to the future changing environment (O'Conner et al., 2008, p. 354).

Non-technical skills and crew resource management

A variety of complex technical professions including industry, medical and the armed forces, focus on equipping people with the appropriate NTS to reduce risks and workload demands (Crichton et al., 2008). NTS can be referred to as the personal, cognitive and social skills that complement an operator's technical skills, to achieve safe and efficient task performance (Flin et al., 2003, p. 96) (Crichton et al., 2008). The European Joint Aviation Authorities (JAA) used NTS in reference to CRM skills defining it as "the cognitive and social skills of flight crew members in the cockpit, not directly related to aircraft control, system management and standard operating procedures" (Flin et al., 2003) (Kanki et al., 2010).

CASA (2011) states CRM training has been utilised as the primary method to provide NTS in aviation; however, "many safety related occupations within aviation do not work as crews, the label NTS training has been introduced as a more general and inclusive term for this form of training."

CRM and NTS training can be considered synonymous, furthermore NTS training is a general term for all training programs in high-reliability industries, designed to improve knowledge and performance in the human dimension of work (CASA, 2011).

Generations of crew resource management

CRM dates back to a 1979 National Aeronautics and Space Administration (NASA) conference, which identified communication, decision making and leadership as critical factors in the human-error component of most aviation accidents. The conference resulted in the term cockpit resource management (later changed to crew resource management) being applied to the training of flight crews, maximising human resources on the flight deck to minimise pilot error (Helmreich et al., 1999, p. 19). Helmreich et al. (1999) states CRM has evolved through five generations since it was first targeted in the aviation industry (p. 20- 29).

First generation cockpit resource management training programs were influenced by corporate training programs that heavily focussed on managerial effectiveness (Helmreich et al., 1999, p. 20). The courses were psychological in nature with a clear focus on correcting individual behaviour and leadership styles (Harris, 2011, p. 258). Pilot attitudes and communication skills were targeted; examples included improving the assertiveness of junior pilots and the authoritarian behaviour of captains (Harris, 2011, p.258) (Helmreich et al., 1999, p. 20). Annual CRM training became part of pilot-training programs; however, many programs encountered resistance, being accused of manipulating personalities (Helmreich et al., 1999, p. 21). In 1986, second generation crew resource management focused on cockpit group dynamics (Helmreich et al., 1999, p. 21). Training programs focused on teamwork, decision making, situational awareness and stress management (Harris, 2011, p.258).

Although CRM training was still largely unrelated to aviation in its demonstration of concepts, trainee acceptance was significantly improved (Helmreich et al., 1999, p. 21).

When crew training correlated with the aviation systems in which they operated in the 1990s third-generation CRM evolved. A clear focus was made on supplying aircrew with specific skills and behaviours, improving efficiency, while integrating CRM with technical training.

While this generation of CRM provided many benefits by extending CRM to encompass all personal within aviation, such as pilots, flight attendants and maintainers, it lost focus on its original objective to reduce human error (Helmreich et al., 1999, p. 21-22).

The fourth generation of CRM was initiated by the Federal Aviation Administration (FAA) forcing flight crews to be trained in CRM and making airlines integrate CRM concepts into technical training (Helmreich et al., 1999, p. 22-23). United States airlines added specific behaviours based on CRM concepts to their checklists. Helmreich et al. (1999) stated that this generation of CRM solved "the problems of human error by making CRM an integral part of all flight operations and training" (p. 23).

A culture change throughout the aviation industry where CRM emphasises error management to minimise inevitable human error, is proposed as the fifth generation of CRM (Harris, 2011, p. 258) (Helmreich et al., 1999, p. 28-29).

The current status of non-technical skills training

In the aviation industry, CRM programs are the primary means of training NTS for cockpit, cabin, dispatch and maintenance crews (Kanki et al., 2010, p.182). According to CASA (2011), Jensen (1997, p.265) and Kanki et al. (2010, p. 182) CRM training provides flight crews with a variety of NTS as displayed in Table 1.

By targeting the operator's NTS, errors are minimised, while improving their ability to identify issues (Crichton et al., 2008, p. 1). CRM courses are heavily regulated at the international level, allowing aviation to lead the charge in NTS training. CASA has published CAAP SMS-1(1) and the Civil Aviation Authority (CAA) has published Civil Aviation Publication 737, mandating course requirements (CASA, 2011) (CAA, 2016).

CRM training is usually taught through a combination of lectures, role playing, case studies and aircraft simulator exercises (O'Connor et al., 2008, p. 354). Initial CRM training has a duration of up to three days, while refresher courses only require half a day (O'Connor et al., 2008, p. 354). Many airlines utilise Line Orientated Flight Training (LOFT) sessions to allow personnel to implement and practise using NTS (Harris, 2011, p. 262). LOFT sessions are usually conducted in flight simulators, allowing the entire crew to train together and respond to various in-flight problems. Instructors overview the training exercise, recording information on how the aircraft and the technical aspects were handled, and how the human dimension was employed to address problems (Harris, 2011, p. 262).

The training effectiveness of a LOFT exercise relies on appropriate training-flight scenarios and the debrief; for maximum benefit, it requires discussion on crew performance covering both positive and negative aspects (Harris, 2011, p. 263). To improve the effectiveness of learning, two briefings occur prior to the exercise; the first explaining the objectives and purpose, while the second is the normal brief explaining the operational context (Harris, 2011, p. 263). These factors assist the crew in understanding the operational context of the exercise, adding to in the reality of the simulation.

Technical failures have been found to be most commonly associated with NTS problems (Kanki et al., 2010, p. 185). The NOTECHS (Non-Technical Skills) framework was developed by the JAA to assess CRM skills across four primary criteria; co-operation, leadership & managerial skills, situational awareness, and decision making (Harris, 2011, p. 258). The framework relies heavily on the examiner "detecting and recording behavioural markers, which indicate the presence or absence of particular NTS" (Moriarty, 2015, p. 8). An individual cannot fail a simulation or LOFT exercise purely on NTS deficiencies, as it needs to be associated with a technical skill

CASA (2011) states CRM training has been utilised as the primary method to provide NTS in aviation; however, "many safety related occupations within aviation do not work as crews, the label NTS training has been introduced as a more general and inclusive term for this form of training.

Cognitive skills	Interpersonal skills	Self-management skills
• Aeronautical decision making • Information acquisition and processing • Situational awareness	• Communication • Conflict resolution • Leadership • Teamwork	• Recognition skills of own and other behavioural styles • Management of: ○ Automation ○ Workload ○ Stress ○ Fatigue

Table 1. Three catagories of NTS

Principle	Description
Principle 1	Only observable behaviour is to be assessed.
Principle 2	NTS are associated with technical skills, thus requiring flight safety to be jeopardised for NTS to fail.
Principle 3	Repetition of an unacceptable behaviour must be observed in order to conclude it's a significant problem.
Principle 4	The overall NTS assessment must be rated as either acceptable or unacceptable.
Principle 5	An explanation is required for each NTS categorised as unacceptable.

Figure 1. The NOTECHS framework utilises five principles to maintain fairness and reliability

Type	Tools/Techniques
Event-based analyses (examining safety reports to identify patterns)	• acciden incident analysis in one's own or similar operations • analysis of confidential reporting systems
Questioning techniques (seeking information directly from workers)	• interviews: structured, unstructured and semi-structured • focus groups • questionnaires and surveys
Observational techniques (watching individuals and teams at work)	• direct: observation by trainer/researcher not engaged in the work at hand • participant: observation by a co-worker • remote (e.g. video and audio recordings)

Table 1. Popular types of tools and techniques used to identify important non-technical skills

failure (Moriarty, 2015, p. 8). For example, a pilot deciding to land at an unsuitable airport, without crew discussion or risk management consideration is both a technical and NTS failure. Kanki et al. (2010) states that the NOTECHS system utilises five principles to maintain fairness and reliability, as listed in ANNEX A (p. 185). "The purpose of non-technical skills assessment is not to pass or fail people purely on their CRM abilities but to provide a better framework for understanding where people's strengths and weaknesses are in this regard and to allow weaknesses to be addressed when they may have an impact on flight safety" (Moriarty, 2015, p. 8). Studies to determine the effectiveness of this NTS assessment have found that 80 per cent of instructors are consistent in NTS marking and 88 per cent were satisfied with the consistency (Kanki et al., 2010, p. 185).

CRM training quality varies considerably, which is a concern when teaching human factors knowledge in high-risk organisations (Moriarty, 2015). To ensure effective NTS training is delivered, CASA (2011) suggests using the five steps detailed in (CAAP SMS-3(1)) to develop an effective training program for organisations. A variety of information sources, tools and techniques are recommended in the identification of training needs as displayed in Annex B.

Analysing training needs, assists organisations in the selection of appropriate training content. Fortunately for the aviation industry there are quality and readily available training resources, that assist in reducing development costs of effective NTS training. The risk of becoming complacent by continually using old resources that may be redundant due to modernisation must be considered. Annex C lists several recommended NTS training topics used by different aviation agencies. The implementation, assessment and evaluation of NTS training programs are all critical criteria that organisations need to invest well in, for the NTS to be effective for personnel (CASA, 2011).

A meta analysis conducted by O'Conner et al. (2008) investigated the effectiveness of CRM training across four areas; reactions, attitudes, knowledge and behaviour. The results determined that people reacted highly to the usefulness of CRM training and found it provided a significant improvement in the attitudes of trainees, in comparison to people who did not receive it (O'Conner et al., 2008, p. 360). The study found a moderate improvement in CRM knowledge for people who undertook training (O'Conner et al., 2008, p. 362). The results displayed improvement in trainee behaviours that were covered in the CRM training; however due to large data-error margins from poor consistency in CRM teaching methods and collation of results, the finding was unreliable (O'Conner et al., 2008, p. 363).

The meta analysis determined there needed to be more rigorous reporting into the evaluations of CRM training because of the increased use of CRM in high-risk organisations. It was recommended that more detailed research be conducted on CRM training to determine its exact effectiveness (O'Conner et al., 2008, p. 366).

Strengths and limitations of non-technical skills training

Conducting NTS training for aviation personnel provides many advantages to the aviation industry, however it contains several limitations. Culture can limit advantages on national, organisational and professional scales. CASA (2016) suggests that the results of NTS training are only effective, if the organisation supports a positive culture and allows personnel to make uncomfortable decisions, such as questioning the aircraft captain when a mistake is made.

Culture influences the delivery and quality of NTS training, especially in developing countries where resources are limited.

Organisations tailor CRM training to their needs; however, variability in the quality of training is a substantial limitation as is skill degradation (O'Conner & Flin, 2003). Although LOFT exercises have proven to be the most beneficial for improving NTS and receiving feedback, the training is limited by skill degradation; retraining needs to occur at least every 12 months (CASA, 2011).

NTS training is largely limited by its ability to improve and according to Kanki et al. (2010) worldwide research "suggests that CRM training without the benefit of data and outcome measurement is doomed to fail" (O'Conner et al., 2008, p. 353-366). A lack of recorded data for CRM training is a central issue in many organisations, preventing researchers determining the clear effectiveness of CRM training and how it could be improved (O'Conner et al., 2012, p. 38).

There are many strengths of NTS training, the primary one being it works by minimising human-factor errors (Flin & Martin, 2001, p. 95-96).

A survey of more than 30,000 airline pilots determined that pilots found CRM courses that integrated CRM principles substantially useful (Beaubien & Baker, 2002). "CRM is one of the success stories of modern psychology and cognitive engineering. While we may not be able to document statistically the number of lives saved by exemplary CRM practices and lives lost through CRM failures, the evidence for the value of CRM cannot be challenged" (Kanki et al., 2010, p. 500).

Although there are limitations in NTS training, the industry has developed measures such as the NOTECHS framework, to provide robust reliability and validity for learning NTS, to positively affect aviation safety and performance (Tsifetakis & Kontogiannis, 2017, p. 1-11).

The future of non-technical skills

CAA (2016, p. 147-154) highlights the need to continually adapt CRM training to the aviation industries changing environment. A significant concern for CRM training is the increased use and reliance of automation within flight crews (De Boer & Dekker, 2017, p. 1).

CRM training needs to adapt to meet challenges as new generations of automated aircraft are introduced; emphasis needs to be placed on the evaluations of reactions, knowledge, attitudes and behaviours to determine the effectiveness of CRM training (O'Conner et al., 2012, p. 38).

To mitigate the negative effects of automation in crew performance, future NTS training needs to invest in determining the negative effects of automation on crew interaction, by continually evaluating it's effectiveness and providing sufficient training, for crews to operate safely and efficiently (De Boer & Dekker, 2017, p. 1-9). Tsifetakis and Kontogiannis (2017) outline that CRM training has not sufficiently integrated technical skills training with NTS training. CASA (2011) states the current configuration of NTS training is primarily knowledge based. Future NTS training needs to focus on

Federal Aviation Authority, United States (2004)	Australian Aviation Operator (2005)	Joint Aviation Authorities, Europe (2006)
• communications processes and decision behaviour • briefings • safety, security • inquiry/advocacy/assertion • crew self-critique (decisions and actions) • conflict resolution • communication and decision-making • team-building and maintenance • leadership/followership/ concern for task • interpersonal relationships/group climate • workload management and situation awareness • individual factors/stress reduction	• human behaviour • human performance limitations • communication • threat and error management • leadership/followership • team co-ordination • situation awareness • judgement and decision making • stress management and fatigue management • workload management and automation • mission analysis and planning • mission briefing and debriefing • organisational and safety culture	• human error and reliability, error chain, error prevention and detection • company safety culture, standard operating procedures, organisational factors • stress, stress management, fatigue and vigilance • information acquisition and processing, situation awareness, work load management • decision-making • communication and co-ordination inside and outside the cockpit • leadership and team behaviour synergy • automation (for type of aircraft) • case-based studies

Table 2. Recommended non-technical skills training topics for three aviation agencies

transitioning from knowledge-based training programs to skills-based training, ensuring a wide range of NTS behaviours that contribute to effective crew performance are delivered (CASA, 2011) (Tsifetakis & Kontogiannis, 2017, p. 1).

Finally it is recommended CRM training is delivered during the earliest stages of flight training, to ensure NTS and the concepts of crew co-ordination are instilled in all aircrew.

Conclusion

It is critical that NTS training continues to deliver increased safety and efficiency to the aviation industry. Various studies have proven that NTS training delivers satisfactory results to participants with large success.

The majority of personnel who undertake current NTS training deem the training as significantly useful. Future NTS training will need to overcome its limitations, particularly cultural and research limitations and adapt training to the increased modernisation of the industry; specifically human factor problems caused by automation.

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2018 Courses

Aviation Safety Training

Course	COURSE AIM:	PREREQUISITES:	COURSE DESCRIPTION:
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ASO (A) Aviation Safety Officer (Advanced) Course	To graduate Base, Wing, Regiment, Fleet, Group and Command ASOs.	ASO (I) Practical and applied experience as a ASO (or equivalent)	The course provides theory and practical exercises in the broad topics of the Defence Aviation Safety Management System, human factors and risk management, and base/unit emergency response. Includes participation in a practical emergency response component.
NTS Aviation Non-Technical Skills Trainer	To graduate students with the knowledge and skills to deliver non-technical skills training.	A solid background in Crew/Maintenance Resource Management and/or Human Factors.	The course provides the theoretical background of aviation non-technical skills and trains students in the skills and knowledge for delivering non-technical skills training. The course also introduces students to scenario-based training and assessment techniques.
AIIC Aviation Incident Investigator Course	To develop members with the skills to conduct aviation incident-level investigations in support of their ASOs.	Any personnel who are involved with Defence aviation. There is no restriction on rank, defence civilians and contractor staff are also welcome to attend.	This one-day course provides theory (taken from the ASO(I) course) on the topics of; the Defence Aviation Safety Management System; generative safety culture; error and violation; the Defence Aviation Safety Analysis Model; aviation safety event investigation and reporting. Interested personnel should contact their ASO.

COURSE NAME /NUMBER	DATES	LOCATION	NOMINATIONS CLOSE
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2/18 ASO Initial	19 to 28 Mar	Canberra	19 Feb
3/18 ASO Initial	10 to 19 Apr	Canberra	9 Mar
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5/18 ASO Initial	21 to 30 Aug	Canberra	20 Jul
6/18 ASO Initial	18 to 27 Sept	Canberra	24 Aug
7/18 ASO Initial	20 to 29 Nov	Canberra	20 Oct
1/18 AvnNTS	30 Apr to 4 May	Canberra	3 Apr
2/18 AvnNTS	6 to 10 Aug	Canberra	9 Jul
3/18 AvnNTS	3 to 7 Sept	Canberra	6 Aug
1/18 ASO Advanced	4 to 8 Jun	RAAF Williamtown	11 May
2/18 ASO Advanced	29 Oct to 2 Nov	RAAF Pearce	5 Oct

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