The Design Principles of Flight Deck Automation and the Occurrence of Active Failures in Aviation

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Abstract

The evolution of advanced technology systems in aviation has seen radically increased capabilities of aircraft, and equally radical changes in how aircraft are flown. Relieving flight crews of much of the manual workloads associated with flying, automation has brought about a shift in the dynamic on the flight deck as the role of crews - who are gradually being removed from direct control of the aircraft - moves towards that of supervisors and managers of the vast array of systems on-board. There is little doubt that automation has provided significant benefits in terms of increased performance, endurance and safety. Yet the sleekness and simplicity of the modern flight deck has proven deceptive. The complexities of aircraft systems, their dependencies and interdependencies, may mask interactions and inhibit the pilot's understanding of systems functionalities. Perhaps just as importantly, as automated systems assumed greater levels of autonomy and authority, the position of automation - and its relationship with those other key players in the cockpit - has not always been explicitly stated. Now managing and overseeing the aircraft's systems, crews, whose exposure to manual flying has been reduced largely to the take-off and landing phases of flight, may be exposed to error causing conditions where they may not understand what the automation is doing.

The aim of this study was to examine the effects of latent conditions (pre-cursor faults) on the occurrence of decision errors, skill-based errors, perceptual errors and violations (active failures / unsafe acts). Based on the ASRS data analysis it was determined that while there was a significant number of automation pre-cursor faults associated with Airbus, Boeing aircraft were more likely to have mechanical related pre-cursor events.

Key Words: Active Failures, Automation, Flight Deck Design, Human Factors Analysis and Classification System

INTRODUCTION

The aviation domain has seen technological advances that would have seemed unimaginable to the early pioneers of powered flight. With greater performance and endurance, aircraft are now flying faster, further, with increased safety and precision, even in the most challenging conditions and environments. Radical changes in the design of aircraft systems, their functions and integration and, more recently, the use of composite materials have enabled these huge leaps in operational capabilities. With the ability to monitor, manage and maintain the aircraft's systems and parameters in flight, even adjusting control surfaces to affect changes to the aircraft's flight profile (Boy, 1998), automation is now somewhat of an indispensable resource.

By performing mundane and repetitive tasks, automation has reduced crew workloads and attentional demands, allowing them to focus on tasks that are of higher priority. As workloads shifted to the automation however, the opportunity for a pilot to manually fly the aircraft decreased. With exposure to manual flying limited, largely, to take-off and landing phases, the crew's opportunity to build and retain the competencies necessary to take control during emergent events is also reduced. Perhaps more worryingly however, should the automation fail or disconnect without warning, crews may not have adequate experience or knowledge of the aircraft's systems to overcome the issue, and reversion to manual mode may test the skills of newer and less experienced pilots (EASA, 2013).

Automation - the consequence of the repositioning of crew authority

Though the improvements in performance and safety have been dramatic, the relentless propagation of automation and automated systems has not been without its problems. As automation became established and reliability was proven, a shift in dynamic occurred on the flight deck as these systems were given more authority and autonomy, and new management and supervisory tasks were imposed on crews (Sarter, 1994). De-skilling and erosion of basic flying skills becomes almost inevitable as the re-allocation of tasks and responsibilities alters the position of the flight crew and the automation assumes a greater role in flying the aircraft. Equally, as flight crews become more dependent on automation, their mental state may also be altered and the potential for human error increases. Over-confidence and complacency may induce a false sense of security as exposure to even the smallest challenge is minimised. Further compounding the situation, whilst many aircraft systems have evolved independently of one another, their integration has not always been seamless, nor has the dependencies and interdependencies of these systems been explicitly stated.

This confluence of factors – the loss of competence, the proliferation and over-reliance on automation and the masking of systems dependencies and interdependencies - can, in situations where it is required to perform manual and automated tasks simultaneously, affect the crew's ability to detect automation failure, resolve difficulties, or take control in the event of systems failures (Billings, 1996; Woods, 2004). Nonetheless, and despite the intricacies and complexities of these systems, flight crews are expected to take control in circumstances where the automation fails or cannot handle a situation.

Airbus versus Boeing - Competing Technologies and Philosophies

While standardisation is sought across the massively complex realm of aviation, a duopoly – Airbus and Boeing – have adopted divergent philosophies with respect to critical features such as flight handling, and levels of automation and crew autonomy. By far the most significant difference between these two manufacturer's aircraft is the positioning of authority and, by extension, the

limitations (or expectations) placed on crews. Within the flight envelope the Airbus 'hard' limit philosophy allows the pilots to make whatever control inputs that they desire, but the aircraft will not go beyond the limits of the envelope. In contrast, the 'soft' limit philosophy adopted by Boeing allows the pilots to exceed the limits of the envelope but, in the process, they will encounter increased control input resistance as they approach and go beyond limits of the envelope (Abbott, 2001).

Active failures and the conditions that predispose pilots to error

Pilots, removed from direct systems control as automation assumes a greater share of physical, perceptual and cognitive roles (Endsley, 1996; Mosier et al., 1997), are now exposed to errors that are perhaps hidden deep within the systems geometries or, perhaps, within computer code. Latent conditions, often embedded in the system for a long time, provide the nexus for active failures on the part of the flight crew. Occurring in the moment prior to an adverse event, errors based on the degradation of skills and knowledge, violations of policies and procedures, or from conditions that affect the crew's perception and decision making (collectively referred to as active failures) become ever more likely where latency has not been identified and addressed.

Where an adverse event occurs the crew's situational awareness may be inhibited where the provenance of the problem is not obvious. As a situation unfolds, crews may act as a catalyst for either recovery or acceleration towards an adverse outcome as their understanding of the event and its causes will influence their actions and reactions. The outcome therefore, as a function of the crews understanding, will be either insignificant, result in an aircraft upset condition, or be further perpetuated as errors are fed back in a cascading loop (Helmreich, Klinect and Wilhelm, 1999).

Failures resulting from degradation or loss of knowledge and skills

Automation bias – over-relying on, or favouring automation generated information over other cues – is another insidious factor associated with the increased use of automated flight systems. Interestingly, automation bias (and the inappropriate decision-making processes based on the potentially flawed information associated with it) is not confined to less experienced pilots, and pilots

with high hours and high exposure to automation are just as likely to experience automation bias (Parasuraman and Riley, 1997). The dangers of an over-reliance on automated systems were perhaps best exemplifies by the American Airlines Flight 965 (a Boeing 757) accident. The crew's attempt to expedite their arrival into Cali, Colombia, their error in not disengaging the aircraft's speed brakes, failure to revert to radio navigation, and confusion caused by the Flight Management System (FMS), all contributing to excessive workload during this critical approach phase of flight, culminated in the loss of the aircraft after it impacted high ground (Aeronautica Civil, 1996).

Lack of Awareness of System Functionality - Asiana Airlines

Given the complexity of the modern aircraft, it is not unexpected that latent factors may become embedded as systems designers attempt to integrate new technology. Despite rigorous testing, a lack of awareness of aircraft systems, their functionality and interactions can occur amongst pilots as an unintended consequence where latency occurs. This inhibited awareness proved deadly when, on 6th July 2013, Asiana Flight 214 (Boeing 777-200ER) on a visual vectored approach, impacted a seawall short of runway 28L at San Francisco International Airport. Though the crew mismanaged the descent and failed to stabilise the approach or initiate a go-around (despite a number of cues), a cascading set of errors caused the pilot to inadvertently override the aircraft's speed protection when he made changes to the autopilot and auto-throttle configuration. This put the aircraft into a rare mode where the auto-throttles – which, even when switched off, can prevent the aircraft from slowing below limits - were disabled. The pilots were found to have over-relied on the auto-throttle system, their understanding of the operation of which was considered to be lacking. The National Transportation Safety Board (NTSB) investigation, however, found that neither Boeing's nor the airline's manuals explained the system and its functions fully. While recommending that the manufacturer revise its' Flight Crew Training Manual (stall protection material), and to address the limitations of the auto-throttles, the NTSB also recommended that airlines should provide training on these aspects (NTSB, 2014). Nonetheless, it is Boeing's stated philosophy that it is the crew who are responsible for the safe operation of

the aircraft, and the flight deck automation is there to aid the pilots, not replace them (Boeing, undated).

Task Saturation and Overload – Air France Flight AF447

Another significant issue often identified in investigation reports is saturation or overload experienced by crews in the lead-up to an accident. Ironically, while the automation on advanced technology flight decks is intended to relieve the workloads on crews, information overload has led crews to commit errors based on information that was not prioritised or conflicted with other cues or information that was present in their environment.

Flight crews can become saturated or overloaded particularly during critical phases of flight or where adverse situations present. This was the case in the event involving Air France Flight AF447. Caught unaware when confronted by conflicting and erroneous data, the crew became increasingly disorientated by what the aircraft was doing. In response to corrupted airspeed data, and without prior warning to the crew, the autopilot and auto-thrust functions disengaged and the aircraft systems reverted to alternate control law - where normal stall protection was inhibited (Geiselman et al., 2013). In an attempt to recover the aircraft, the First Officer initiated a series of inputs that, unknown to the crew, brought the aircraft to aerodynamic stall. As the situation escalated, confusion over control authority saw both pilots making conflicting inputs on their respective side-stick. In the minutes before impact the Angle Of Attack (AOA) exceeded 40°, and the aircraft lost altitude at a rate of 10,000 feet per minute (BEA, 2012).

Methodology

The largest repository of de-identified aviation reports in the world (NASA, undated), NASA's Aviation Safety Reporting System (ASRS) has been used as a basis for many research studies (Connell and Reynard, 1993; Funk and Wilson, 1998; Bliss, 2003).

Content Analysis

A search of the ASRS database found over 7,300 reports submitted by crews of Airbus aircraft, and in excess of 18,000 reports submitted by crews of Boeing aircraft on the database. As the aim of this research was to determine the effects of automation on Airbus and Boeing flight crews, it was decided that an iterative process would enable the researcher to confine the search parameters and select a sample for analysis.

With the search criteria confined, a follow-up search determined that there was just over 4,500 Airbus and slightly more than 16,000 Boeing reports relating to automation. These reports were analysed using a content analysis package. A data mining and textual analysis tool used for identifying word usage, themes and trends, content analysis software is specifically suited to the analysis of unstructured qualitative data. Despite the utility of this type of software, the researchers were careful not to draw inference from the outputs generated by the software (Hsieh and Shannon, 2005). From this analysis the search was honed over a number of iterations until, finally, 188 ASRS reports (94 Airbus and 94 Boeing reports) were selected for analysis for this study.

HFACS - Analysing the ASRS Reports

The Human Factors Analysis and Classification System (HFACS) taxonomy was used to identify latent and active conditions in the 188 extracted reports. HFACS provides a mechanism to identify and categorise not only human error but multiple higher level factors that may have lain dormant in the lead-up to an adverse event. Such information taxonomic systems are suited to analysis of the factors that precipitate an event (Shappell and Wiegmann, 2000; Stanton and Salmon, 2009). The ASRS data were coded using the HFACS taxonomy and analysed to determine the extent of active failures (violations, perceptual errors, skill-based errors or decision based errors) present in the reports. The main researcher on this paper has developed vast knowledge and experience using HFACS during occurrence investigation and analysis, and peer review of his methodology has demonstrated consistency in its application. Inter-rater reliability, therefore, was proven by this peer review oversight.

Statistical Analysis

The data were cross-tabulated and analysed using Chi-square (χ2) analyses to determine if there was any statistical association between the variables identified. Goodman and Kruskal's Tau (τ) was used to test the strength of association found between these variables.

RESULTS AND DISCUSSION

Of the 188 ASRS reports analysed 178 were to deemed valid for the study – it was not possible to determine the cause on four reports, and six more were discounted as the cause was determined to be outside the parameters of the study (weather related or other factor, but no automation related factors).

While a significant number (58%) of automation related pre-cursor events occurred on Airbus aircraft (p=0.022; τ=0.015), significantly more mechanical pre-cursor issues (65%) occurred on Boeing aircraft (p=0.25; τ=0.017) (Table 1).

Table 1. Pre-cursor Fault Types versus Aircraft Manufacturer

	Airbus n(%)	Boeing n(%)	Total n(%)	Chi-square Value	P	τ	Odds ratio
Automation	61 (57.5)	45 (42.5)	106 (100.0)	5.971	0.022	0.015	NS
Mechanical	16 (34.8)	30 (65.2)	46 (100.0)	5.746	0.025	0.017	2.320
Automation/ mechanical	5 (29.4)	12 (70.6)	17 (100.0)	NS	-	-	-
CRM	7 (77.8)	2 (22.2)	9 100.0)	NS	-	-	-
Total	89 (50.0)	89 (50.0)	178 (100.0)			NS = Not Significant	

In total, 40 events were identified as involving unsafe acts (active failures) - 18 of these events involved decision errors, 11 violations, 9 skill-based and 2 events involved perceptual errors (Table 2).

Automation pre-cursor faults were responsible for the majority of violations (55%), 36% of violations occurred as a result of mechanical pre-cursors, and auto / mechanical issues account for the remaining 9% of violations.

All perceptual errors (100%) occurred because of automation.

The majority of skill-based errors (44%) occurred as a result of an automation pre-cursor, Crew Resource Management (CRM) was responsible for 33%, and the remaining 22% of skill-based errors occurring as a result of mechanical pre-cursor faults.

Automation related pre-cursor faults accounted for 44% of decision errors while mechanical pre-cursors accounted for 39%. CRM related pre-cursor faults (17%) were least likely to result in decision errors.

Overall, automation pre-cursors accounted for the majority (48%) of unsafe acts, mechanical for 35%, and CRM for 15%. Automation/mechanical pre-cursors were responsible for the least number of unsafe acts.

Table 2 Pre-cursor Fault Type resulting in Unsafe Acts

	Violation n (%)	Perceptual Error n (%)	Skill-Based Error n (%)	Decision Error n (%)	Total
Automation	6 (54.5)	2 (100.0)	4 (44.4)	7 (38.9)	19 (47.5)
Mechanical	4 (36.4)	0 (0.0)	2 (22.2)	8 (44.4)	14 (35.0)
Auto/Mech	1 (9.1)	0 (0.0)	0 (0.0)	0 (0.0)	1 (2.5)
CRM	0 (0.0)	0 (0.0)	3 (33.3)	3 (16.7)	6 (15.0)
Total	11 (100.0)	2 (100.0)	9 (100.0)	18 (100.0)	40 (100)

Active Failures in the Descent Phase of Flight

The modern flight deck, with its vast array of systems, is testament to the success not only of human-centred design philosophies but to the ingenuity of the hardware and software engineers who design and develop these systems. Increasingly however, as automation assumed greater levels of responsibility, the re-allocation of tasks from man to machine has seen crews further removed from critical flying functions. This, and an accumulation of other factors have, over time, obscured the position of crews and their role in this complex socio-technical environment. Underlying an aircraft's automation are systems dependencies and interdependencies that often the pilot do not understand and, some would argue,

do not need to understand. This decoupling of pilots - due to high levels of automation - removes them not only from the process (IAEA, 1992) but can potentially lead to degraded awareness of the system's state. Where a problem manifests, and the provenance of a fault is not clear however, the crew's awareness of the underlying cause may inhibit their ability to predict its path and take corrective action. In such cases, unexpected shifts in attentional demand associated with the aircraft's automation can lead to increased cognitive demands, information overload and task saturation as the crew try to re-orient to the changing state of the system (Sarter and Woods, 1995). The potential for these latent pre-conditions (Level 2, 3 and 4 - latent failures) to influence decisions, skills, and perception and, in extreme cases, the commission of violations (Level 1 - active failures) becomes ever more likely.
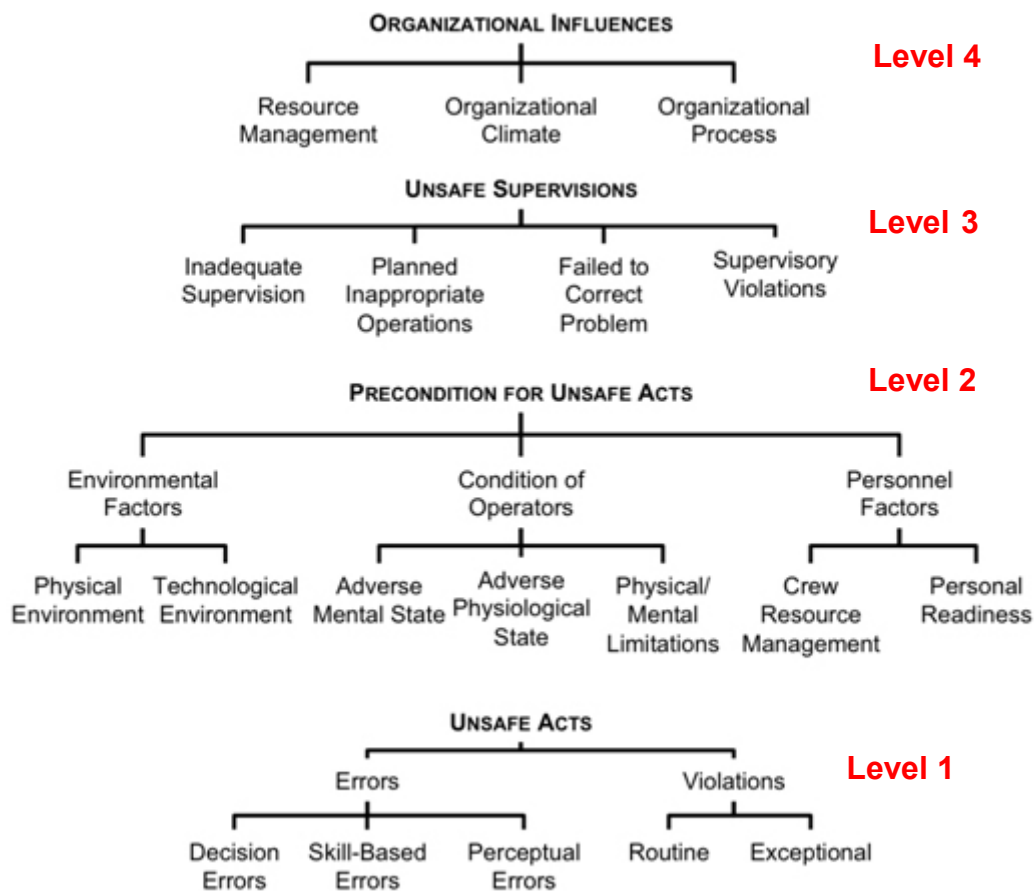
Source: hfacs.inc, 2014

Figure 1 Latent factors that may act as pre-cursors to active failures (Unsafe Acts)

Analysis of the ASRS data showed that, of the 46 events involving mechanical pre-cursors, significantly more events occurred on Boeing than on Airbus aircraft.

In contrast, of the 106 automation related pre-cursor events, a greater number occurred on Airbus aircraft than on Boeing, Table 1. Notwithstanding this, and despite the divergence associated with their respective design philosophies, particularly the 'soft limit' (Boeing) and 'hard limit' (Airbus) elements, the evidence does not indicate that the philosophies or automation acted as pre-cursor or had an adverse impact on crews. Perhaps the culmination of the decreasing trend in errors occurring on advanced technology aircraft identified by Funk and Wilson (1998), and somewhat exonerating and confirming the utility of the human-centred design approach used by both manufacturer, unsafe acts did not prove significant in the events analysed (Table 2). Nonetheless, the complexity of aircraft systems and their integration may give rise to opacity issues that can inhibit the crew's awareness of and ability to intervene to resolve a problem (Durso et al., 2011). The accidents involving Asiana Flight 214 and Air France Flight AF447, in fact, demonstrate that impoverished awareness of the underlying systems functionality and the relinquishing of authority by the automation back to the pilots, are not problems of the past but are still present on the modern airliner. Crews, unable to track what the automation is doing, may be surprised where the automation behaves in a way that they do not understand or expect (Sarter and Woods, 1995). While the limitations of human capacity are difficult to predict - particularly in a dynamic situation - the adaptability and flexibility of the crew to detect and trap an error is, nonetheless, their strength (Orasanu, Martin and Davison, 1997).

Aircraft Manufacturer and Design Philosophy

The different philosophies adopted by two manufacturers is an ongoing source of debate. Though somewhat of a paradox in a highly standardised sector, these divergent philosophies, it is proposed, were driven by the need to differentiate one manufacturer's aircraft from the others, thus avoiding price wars in this highly capital-intensive industry (Beckman, 2003; Ibsen, 2009). Interestingly, and perhaps grounded in their own understanding of the aircraft, pilots tend to favour the aircraft that they themselves fly. One study found that pilots commented on the Boeing and Airbus philosophies in a manner that reflected their experience on, and their preference of, a particular aircraft. Pilots in that study commented

that Boeing "…keeps the pilot in the picture…", while in contrast, Airbus "…tries to remove" the pilot from the equation. Furthermore, despite comments that generally endorsed the "when in doubt use the automation" philosophy, some pilots consider that "Airbus should have a… switch to give the pilot full authority of flight controls if needed" (Mitchell, 2009, pp. 25-26). Another study involving Airbus, Boeing, and McDonnell Douglas pilots did not find a difference in responses to the design philosophy question, but instead found that Airbus pilots were the only ones who favoured the protection provided by the 'hard' limits performance envelope protection (Tenney, Rogers and Pew, 1995). Divergent opinions are noticeable even on the issues of usability, control authority and the level of level of autonomy. Some reporters commented that features of Boeing's automation are easier to use, while others considered that the Airbus 'pilot flying / pilot monitoring' approach was the way forward.

What is clear from the ASRS reports examined for this study however, is that many crews stated that they were unsure as to why an event occurred and, more often than not, remained unaware of what led to the issue arising in the first place. In a number of reports analysed, the pilots have asked "why did this happen?", or stated that "I am at a loss to explain what happened". One First Officer (FO) in fact had, on a number of different occasions, encountered a pitch-up initiated by the autopilot resulting in a decrease in speed. When he discussed the issue with the (different) Captains involved on each occasion, the FO said that the overwhelming response was "well, it's a -300" (a reference to a peculiarities of the Boeing 737-300 Series aircraft). It is vital for crews to have an understanding of systems integration and dependencies, as well as the control logic used, in order to ensure that they are not surprised by the automation (Boy, 1998). Furthermore, while it has been proposed that pilots should be the ultimate arbiter when it comes to control authority, a deeper understanding of the underlying technology would go some way to enable an understanding of those over-arching manufacturer's philosophies (Mitchell, 2009).

Recent events have shown that pilots can become confused by subtle mode switches, or where the automation disconnects a system unexpectedly. Undoubtedly, pilots should be armed with the skills, knowledge and experience to enable them to take control when facing adversity. Training for adversity

enables crews to attain and retain competence, build the mental models and the heuristics that make decision making easier. Detecting deviations is more likely where the system deviates from expected behaviour rather than when, without explicit input or command from the pilot, the system initiates an unexpected action (Sarter and Woods, 1995).

Conclusion

There is little doubt that automation has made flying safer, more efficient, and led to increases in performance that would have seemed unimaginable just a few decades ago. Paradoxically, however, the changing skillsets required to operate on the modern flight deck, coupled with the reliability of automated systems, has had an adverse effect on crew performance. Poorly considered flight deck and systems designs has caused issues in the past, and the haphazard integration of these systems has led some to question the motivation for the use of automation. As far back as the late 1970s, it was suggested that the evolution and proliferation of automation in the cockpit was driven not by consideration of the role of flight crew, but by engineering feasibility analyses and costings (Edwards, 1977). Though it took some time for human-centred design philosophies to gain traction, increasingly we are seeing the benefits of automation acting as an aid to pilot skills.

There is a stark contrast between Airbus' hard limit philosophy and Boeing's soft limit philosophy. Though significantly more automation related events occurred on Airbus than Boeing, it was interesting that significantly more mechanical related events occurred on Boeing than on Airbus aircraft. While it was not otherwise possible to ascertain how the two diverse design philosophies affected an event, there was no evidence to suggest that either manufacturer's automation was a significant factor in the occurrence of these events. Nonetheless, while flight crews are still required to manage and operate the aircraft's systems, more and more, they are further removed from direct control of the aircraft. Aircraft manufacturers and systems designers must ensure that the integrity of aircraft systems is robust and that customers – airlines and crews – are aware of the fundamental philosophies before deploying into the live environment. Equally, it is incumbent on airlines to ensure that their crews are

trained, and retain the necessary skills and knowledge to operate the aircraft safely.

Despite the scale and forms of divergences between these two manufacturers, there appears to be a lack of research on these diametrically opposing philosophies. Any comparisons made here, therefore, must be tempered by this fact. It is suggested that this study be built upon in an effort to establish data on the effects of automation and awareness of design philosophy on pilot behaviour, and the occurrence of active failures in flight operations. Further research in this area may provide an insight into these issues.

REFERENCES

Abbott, K.H. (2001). Human Factors Engineering and Flight Deck Design Handbook. In: Spitzer, C.R. Ed. *The Avionics Handbook.* Boca Raton: CRC Press LLC.

Aeronautica Civil, (1996). AA965 Cali Accident Report- Near Buga, Columbia, December 20, 1995. Colombia: Aeronautica Civil.

BEA (2012). Final Report On the accident on 1st June 2009 to the Airbus A££)-203 registered F-GZCP operated by Air France flight AF 447 Rio de Janeiro – Paris. Bureau d'Enquêtes et d'Analyses, Paris, France.

Beckman, S.R. (2003). Cournot and Bertrand Games. *The Journal of Economic Education.* Vol. 34(1):pp. 27-35.

Billings, C.E. (1996). *Human Centered Aviation Automation: Principles and Guidelines (Tech. Mem. Np. 1103981)* Moffett Field, California: NASA Ames Research Center.

Bliss, J.P. (2003). Investigation of Alarm-Related Accidents and Incidents in Aviation. *The Journal of Aviation Psychology.* Vol. 3(3): pp. 249-268. http://dx.doi.org/10.1207/S15327108IJAP1303_04

Boeing (undated). *Human Factors.* Web article. Available from: http://www.boeing.com/commercial/aeromagazine/aero_08/human_textonly.html [Accessed: 25 June 2016]

Boy, G. A. (1998). Cognitive function analysis for human-centered automation of safety-critical systems. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 265-272). ACM Press/Addison-Wesley Publishing Co.

Connell, L.J. and Reynard, W.D. (1993). Emergency Medical Services helicopter incidents reported to the aviation safety reporting system. *NASA-Ames Research Center, Moffett Field, California, USA.*

Durso, F. T., Feigh, K., Fischer, U., Morrow, D., Mosier, K., Pop, V. L., Sullivan, K., Blosch, J., & Wilson, J. (2011). *Automation in the Cockpit: Toward a Human-Automation Relationship Taxonomy (HART-16).* Washington, DC.

EASA, (2013). *EASA Automation Policy Bridging Design and Training Priniciples.* EASA, IGPT.

Edwards, E. (1977). Automation in Civil Transport Aircraft. *Applied Ergonomics.* Vol. 8.4:pp. 194-198.

Endsley, M.R. (1996). *Automation and Situation Awareness.* In: Parasuraman, R. and Mouloua, M. (Eds.). *Automation and Human Performance: Theory and Applications.* (pp. 163-181). Mahwah, NJ: Lawrence Erlbaum.

Funk K. and Wilson, J.R. (1998). The Effect of Automation on the Frequency of Task Prioritization Errors on Commercial Aircraft Flight Decks: An ASRS Incident Report Study. In Proceedings of *2nd Workshop on Human Error, Safety, and System Development, April 1-2, 1998*.

Geiselman, E.E., Johnson, C.M., Buck, D.R. and Patrick, T. (2013). Flight Deck Automation: A Call for Context-Aware Logic to Improve Safety. *Ergonomics in Design: The Quarterly of Human Factors Applications.* Vol. 21(13).

Helmreich, R.L., Klinect, J.R., & Wilhelm, J.A. (1999). Models of threat, error, and CRM in flight operations. *In Proceedings of the Tenth International Symposium on Aviation Psychology* (pp. 677-682). Columbus, OH: The Ohio State University.

hfacs.inc, (2014). The HFACS framework. Website. Available from:

http://hfacs.com/hfacs-framework.html [Accessed: 08 August 2016]

Hsieh, H-F and Shannon, S.E. (2005). Three Approaches to Qualitative Content Analysis. *Qualitative Health Research.* Vol. 15(9): pp. 1277-1288. DOI: 10.1177/1049732305276687.

IAEA (1992). *The Role of Automation and Humans in Nuclear Power Plants.* Austria: International Atomic Energy Agency.

Ibsen, A.Z. (2009). The Politics of Airplane Production: The Emergence of Two Technological Frames in the Competition Between Boeing and Airbus. *Technology in Society.* Vol. 31:pp. 342-349. DOI: 10.1016/j.techsoc.2009.10.006.

Mitchell, J. (2009). Flying Glass: A Qualitative Analysis of Pilot Perceptions of Automated Flight Decks after 20 Years. *International Journal of Applied Aviation Studies*. Vol. 9:pp. 13-29.

Mosier, K.L., Skitka, L.J., Heers, S. and Burdick, M. (1997). Automation Bias: Decision Making and Performance in High-Tech Cockpits. *The International Journal of Aviation Psychology.* Vol. 8(1):pp.47-62.

NASA (undated). *ASRS Database Online.* Webpage. Available from: http://asrs.arc.nasa.gov/search/database.html [Accessed: 21 May 2016]

NTSB (2014). Crash of Asiana Flight 214 Accident Report Summary. Webpage. Available from: http://www.ntsb.gov/news/events/2014/asiana214/abstract.html [Accessed: 25 June 2016]

Orasanu, J., Martin, L. and Davison, J. (1997). Errors in Aviation Decision Making: Bad Decisions or Bad Luck? U.S.: NASA – Ames Research Center.

Parasuraman, R. and Riley, V. (1997). Human and Automation: Use, Misuse, Disuse and Abuse. *Human Factors: The Journal of Human Factors and Ergonomics Society.* Vol. 39(2): pp. 230-253. doi: 10.1518/001872097778543886

Sarter, N.B. (1994). *Strong, Silent, and 'Out-of-the-Loop'": Properties of Advanced (Cockpit) Automation and Their Impact on Human-Automation Interaction.* (Electronic Version) PhD Dissertation. Ohio State University. Available from:

https://etd.ohiolink.edu/rws_etd/document/get/osu1241100682/inline [Accessed: 01 June 2016]

Sarter, N.B. and Woods, D.D. (1995). How in the World Did We Ever Get Into That Mode? Mode Error and Awareness in Supervisory Control. *Human Factors: The Journal of Human Factors and Ergonomics Society.* Vol. 37(1):pp. 5-19.

Shappell, S.A. and Wiegmann, D.A. (2000). *The Human Factors Analysis and Classification System (HFACS).* Washington: FAA.

Stanton, N.A. and Salmon, P.M. (2009). Human Error Taxonomies Applied to Driving: A Generic Driver Error Taxonomy and its Implications for Intelligent Transport Systems. *Safety Science*. Vol. 47:pp. 227-237. DOI: 10.1016/j.ssci.2008.03.006.

Tenney, Y.J., Rogers, W.H. and Pew, R.W. (1995). *Pilot Opinions on High Level Flight Deck Automation Issues: Towards the development of a Design Philosophy.* United States: NASA.

Woods, S. (2004). *Flight Crew Reliance on Automation – CAA Paper 2004/10.* UK: CAA.

2017-04

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