Human-Machine Interaction in the Cockpit and Applicable Design Changes Towards Better Collaboration

Aysen Taylor

Abstract Current flight deck automation has improved the safety and efficiency of commercial aviation but a broad consensus has developed over the last 20 years that this technology is deficient in some areas. It has been developed in an ad hoc manner and without a human centered approach; leading to problems regarding the human/machine interaction and adversely impacting decision making throughout the flight. Current procedures and design do not give automation liability although it has great authority and autonomy during most phases of flight. Cockpit automation has not been designed in such a way to provide adequate and unambiguous feedback to the human operator as to its current and intended actions. More or different training is the most common response to this problem but has failed to fully compensate for the design flaws in current automated systems. Accidents that cite pilot error do not always acknowledge how difficult it is for human operators to overcome fundamental, system level, flaws in the design of the machines they work with. This paper proposes some changes in cockpit automation design that will improve the vigilance of the pilots and therefore create better decision-making. Numerous accident and incident reports have been cited by regulatory authorities when making changes in automated flight operation regulations. This reflects a "reactive" approach to FAA automated flight safety guidelines and highlights the need for an improved governance system in the cockpit. This paper also provides a literature review for current studies on human-machine interaction related to the cockpit.

Keywords Cockpit automation · Decision making · Governance

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1 Introduction

Early aviation featured aircraft utilizing direct mechanical linkages to the control surfaces which provided pilots with constant feedback through their hands and feet. Pilots manually manipulated the throttle and engine noise provided feedback as to its status. This arrangement proved to be physically demanding and inadequate as aircraft range and service ceilings grew. Longer flight times and flights in poor visual conditions warranted the development of autopilot systems and new flight instruments for the pilot to help them maintain a given heading and altitude. Loss of the visual horizon at night or in poor weather could be compensated for through use of an attitude indicator in the cockpit. The first and second World Wars brought rapid growth in airplane technology and avionics. New guidance systems were developed to improve bombing precision. Advances in autopilot systems were complemented with the development of ground based navigation aids using radio beacons and these were later tied to autopilot systems. Each new iteration of autopilot and navigation aids improved operational precision and efficiency.

As pilots direct control of the aircraft slowly gave way to indirect control, the unrecognized trade off was loss of aircraft state feedback to the pilots as more flight path management duties passed to the autopilot. Edwards raised concerns of potential problems with automated cockpits [1, 2]. Current generation airliners have 80 % of their functionality enabled by software while earlier aircraft from the 1960s had 10 % [3]. These avionic systems were commonly developed in an ad hoc fashion, without consideration of how sub-components interact and with little consideration for the principles of systems engineering. Degani and Wiener [4] studied the airline cockpit as a complex human-machine system and discussed the impact of operational management of the organization on this system. Airline companies developed detailed procedures for pilots to follow as a way to standardize the methods for completing common flight tasks in a logical and efficient manner. Their study found that pilots often vary greatly in some aspects from the standards mandated by their organizations. They blamed this more on the ways procedures were developed than on the pilots. While Standard Operating Procedures (SOP) have a role in aviation, over reliance on them can reduce the role of the human operator and therefore reduce the benefit provided from human operators who can reason when presented with novel situations for which there is no SOP.

Accident and incident reports over the last twenty years cite more problems with the human-machine interaction in these advanced aircraft and use of the term automation surprises [5] became more common. Many advocated for changes to training protocols to overcome shortfalls in airline operations of automated cockpit systems. While this technology was given more autonomy and authority it was not adequately designed to provide sufficient and unambiguous feedback to the human operator as to its current and intended actions. Humans and machines will never be infallible but mishaps from their inability to work collaboratively can best be reduced through improved designs of cockpit automation systems and sound decision governance of pilot-automation interactions.

1.1 History of Automation in Aviation

Early aircraft systems utilized a pilot who moved controls, thus changing the control surface positions and altering airflow, which changed the flight path. Technology was later added to improve accuracy in navigation and reduce physical fatigue on pilots. This improved efficiency while reducing the pilot's direct control of their aircraft. A new hazard was created as the autopilot would happily fly the plane into a mountain without human intervention. The introduction of Flight Management Computers (FMC) required pilots to program waypoints along a planned flight path and enter performance data such as pounds of fuel loaded, runway length, and local barometric pressure readings. The FMC was later tied to the auto throttle controls. With each new layer of automation the pilots lost more direct control of the plane and had more difficulties getting and interpreting feedback from automation [6].

1.2 Regulatory History

The US Army established a flying school near San Diego in 1912 and established the first organized oversight of aviation [7]. The Contract Air Mail Act of 1925 started an innovative postal program that later served as a model for commercial air operations [8]. Various Federal agencies had oversight of airline operations and ultimately culminated in the formation of the National Transportation Safety Board (NTSB) as the investigative arm which suggests rulemaking to improve safety to the Federal Aviation Administration (FAA) [9]. The FAA has sole purview of rulemaking and enforcement relating to civil air operations. They also oversee a certification process for new aircraft models and related subcomponents such as autopilots, to ensure safety. The 1978 Airline Deregulation Act was passed by Congress to promote competitive market forces in the industry [10] and ushered in a host of low cost carriers to compete with legacy carriers such as American, United, and Delta.

1.3 Aeronautical Decision Making and Risk Management

The FAA defines aeronautical decision making (ADM) as the "Systematic approach to the mental process used by aircraft pilots to consistently determine the best course of action in response to a given set of circumstances" [11]. The FAA places ADM in the broader context of risk management. Noyes, [12] discussed the impact of complex automation on existing models of ADM. She stated "too much automation, and the human operator is not in the loop when failures and malfunctions occur. Making decisions thus becomes problematic as crew are not fully aware of the situation." She further elaborated by saying "the challenge for system design concerns the development of systems, which provide an appropriate level of automation for a particular situation at a given time."

1.4 Two Design Philosophies, Boeing Versus Airbus

Boeing and Airbus dominate manufacturing of large commercial transport aircraft today and their design choices have great influence over other makers and tend to set standards. Boeing introduced the glass cockpit 757 and 767 in the early 1980s and committed the company to using analogue gauges only in a supporting role. They updated the 737 and 747 models with glass cockpits and introduced the fly-by-wire 777 and 787. These advances in technology allowed aircraft to navigate using satellites and on-board equipment. This brought performance-based navigation (PBN), which reduced average flight times, improved fuel efficiency, and is widely credited with reducing accident rates compared to air transports only operating with ground based sensors for navigation guidance [13, 14].

Airbus introduced the first fly-by-wire airliner in 1988 with their A320. This approach provides flight envelope protections which limit the pilot's input when these place potentially damaging G forces on the airframe or lead to an angle of attack that would cause a stall to manifest. This technology also lowered maintenance costs and reduced training times.

Boeing and Airbus each have published automation philosophies; the key difference being that Boeing takes a more pilot centric approach. In both designs, automation will override or resist the pilot at the outer limits of the flight envelope. Airbus has a marginally greater number of these override systems and they activate slightly sooner. Airbus uses a sidestick while Boeing uses a traditional yoke. This yoke uses a stick shaker during a pre-stall event and will push forward automatically if a stall manifests. The sidestick does not do this and they are also not slaved to each other as the yokes are and thus one pilot cannot know what inputs the other pilot is applying. When the aircraft is operating in full automation, the Boeing throttles and yokes move to reflect inputs from the autopilot but the sidestick and throttles in an Airbus do not move while under autopilot control. Airbus recently received a patent for a design featuring a windowless cockpit as seen in Fig. 1.

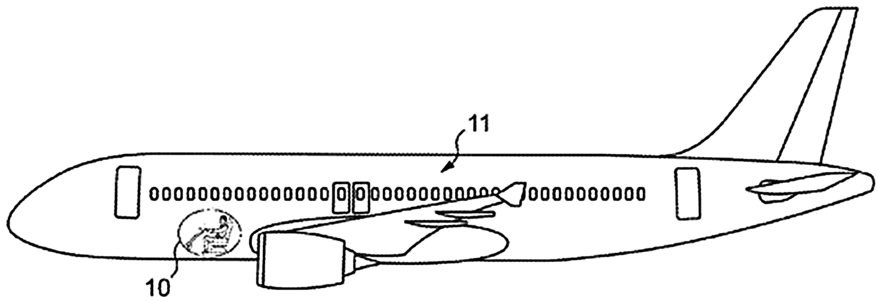

Fig. 1 Airbus' new design to eliminate pilot's natural vision (U.S. Patent No.2014/0180508A1, 2014)

1.5 CRM and Its Implications for Cockpit Automation

Crew Resource Management (CRM) has been a core element of initial and recurrent pilot training for decades. It requires crew members to work together as a team and not show undue deference to a senior pilot and be ready to speak up when one thinks standard operating procedures (SOP) are not being followed [15]. The opaqueness of automation and lack of consistent feedback to the pilots has made it difficult to utilize CRM principles and include cockpit automation as part of the team. Pilots may have trouble recognizing and recovering from automation failures and trying to do so increases workload significantly.

2 Problems with the Current Flight Deck

Previous research on problems with cockpit automation fall into one of several categories. Automation has impacted workload by lowering workload where it was already low and increasing it where it was already high [16]. Various working groups comprising all or most major stakeholders in commercial transport aviation conclude workload is reduced during normal operations but can increase in non-normal circumstances such as a last minute runway change from Air Traffic Control (ATC) as use of the automated systems may increase task complexity and workload on the pilots. Pilots can lose their cognitive model of what the plane is doing while under automated control and this leads to a phenomenon called automation surprises [5, 17]. This situation awareness issue is sometimes more narrowly focused in the literature as mode confusion referring to the many possible mode configurations in the FMS [18].

A common concern in studies over the last 20 years is the degradation of manual flying skills of pilots who operate their aircraft at a high level of automation during most phases of flight [19]. How to improve training to help pilots better utilize automation is a topic of long standing but more recently Geiselman et al.

emphasized [20] that better training is only a partial solution and they call for "a more context-aware automation design philosophy that promotes a more communicative and collaborative human-machine interface." The autopilot systems in use have a myriad of possible configurations, which makes it difficult for the pilot to understand what mode is in force at any given time. A diagram of these modes is shown in Fig. 2.

2.1 Lack of Governance for Automation

Inadequate governance has been identified as an obstacle to improving safety in highly automated commercial transports. Reidemar [21] highlighted the gap between operational policy and practices on the flight deck. She emphasized that the manufacturers' automation philosophy is only about design and says little about operations. Poor guidance is being provided for training, procedures, and the division of labor. She cites problems related to varying policies and cultures among different carriers and calls for a unified policy that "provides general principles for human-automation interaction in the cockpit and all other aspects of operations." The current regulatory model governing cockpit automation/pilot interaction is outdated, ad hoc, fragmented, and may inhibit advances needed to improve safety [22].

3 Need Input from Automation to Improve Pilot's Situational Awareness and Vigilance

When considering broadly how to improve safety and efficiency in commercial aviation, making automation more of a team player should be a primary goal. The process of updating avionics is lengthy and the question arises of how to improve the automation system without making an entire redesign, which would be costly, time consuming, and require much additional training. Some add-on applications should be considered to make improvements until basic design changes can be created and implemented to update current automated systems. Several fatal commercial aviation crashes including Air France 447, Air Asia 8501, Asiana 214, and Colgan Air 3407 have shown that a large obstacle to pilots applying their airmanship skills is automation dependency and overreliance. Once automation had reached its performance limits, it can abruptly disconnect and shift total responsibility to the pilots, often with little or no guidance as to the last state of the aircraft. Sometimes pilots are confused over the course of routine flights as automation can lead to them being out of the control loop. Cockpit voice recordings reveal comments such as "what is it doing now?", "are we descending or ascending?", and "I don't understand why it's pitching up", etc. If a supplemental piece of automation is

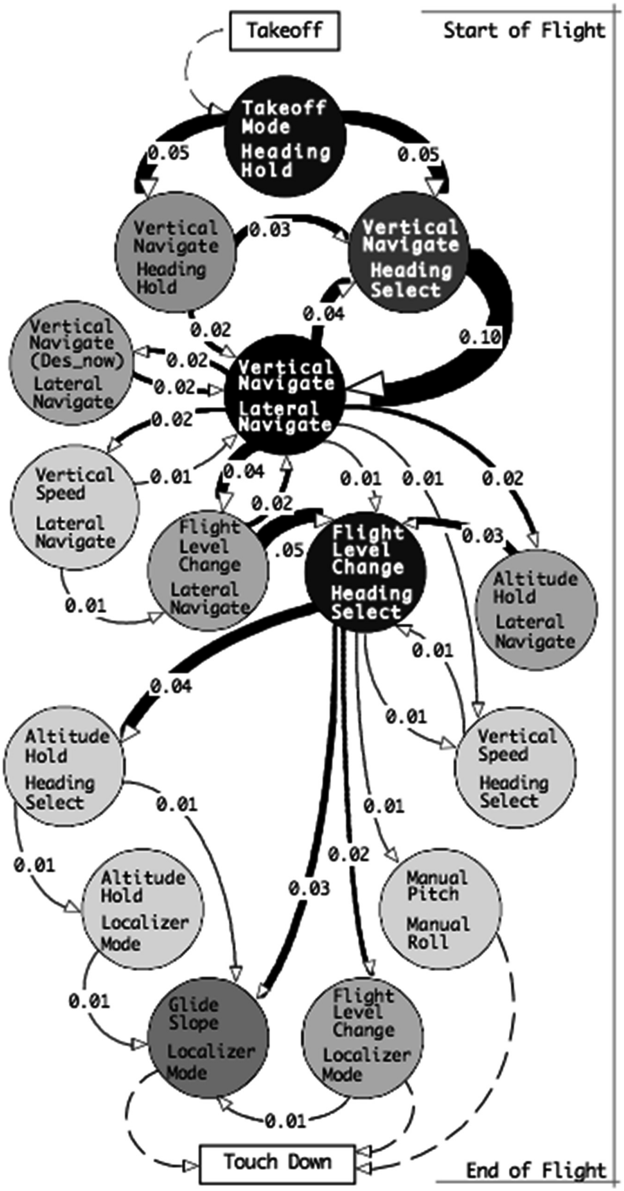

Fig. 2 Diagram of various autopilot mode configurations over the course of a flight. "Modes in automated cockpits: problems, data analysis, and a modeling framework", Degani et al. [18]

provided that helps the pilots maintain awareness of aircraft state, this could help them act correctly and swiftly when they must suddenly take manual control of their aircraft. A survey conducted amongst airline pilots clearly makes us believe that automation has made the pilot's life easier (75 out of 77 survey respondents said this) but the same survey revealed that 37 % of pilots are sometimes surprised by the actions automation takes. We believe if pilots are engaged with their aircraft throughout the flight, it will improve safety and therefore more research is needed in this direction.

4 Conclusions

While automation in the cockpit has reduced accident rates and improved efficiency, there are some prominent accidents in the last decade that point to issues of inadequate feedback between automation and the pilot crew. A new generation of pilots is coming online with far less experience in manual operation of flight controls and the risks associated with sudden autopilot disconnections may increase. The governance process relating to certification of flight path management systems should better account for the recognized hazards identified in the literature about cockpit automation over the last 30 years. Pilots are not less important today, indeed, they are the most critical last line of defense when it comes to aviation safety but they need better interfaces with their plane's computers and automation must be made to conform to the principles of CRM that pilots are expected to adhere to. Boy emphasized that human reliability should be considered from two vantage points; humans have limitations but humans are also uniquely suited to solve novel and unexpected problems [23] and we need to value this crucial component of the system.

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