ERRORS FROM ENGINEERING IN FLIGHT SAFETY

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Abstract

The use of automated systems in aircraft has increased in the last years in order to improve its performance characteristics as well as to amend flight safety, avoiding failures during its operations. The systems have been used as a strategy to mitigate flight accidents related to human factors since it does generate substantial material and human damages when it occurs. It was ascertained that despite the improvements and increase of automated systems on aircraft, there are still a significant number of accidents in civil aviation annually. Analyzing surveys from different sources, it can be noted that the pure application of the new technologies is not enough to generate a drastic reduction in the number of aerial accidents. This is explained by the fact that such automated systems bring with them the need for greater capacity on the part of the crew to understand them so that the pilot is able to perform the proper monitoring during an operation. Thus, it can be concluded that the application of the automated systems in aircraft is generating new types of human errors inside the cockpit, which must be analyzed from a new perspective. Due to the new forms of error that have arisen inside the cockpit, the importance of the application of interdisciplinary knowledge of both the pilots and engineers has increased, improving the understanding of the relationship between the systems and their knowledge bases. The purpose of this article aims to demonstrate that the errors of action, decision and those of cognitive origin, did not reduce with the aircraft automation.

1 Introduction

Automatic systems are those that have the capability of information feedback in order to verify its own functioning, making the necessary corrections without the need for human interference. These systems have been increasingly used, since automation in many cases is able to exceed human capabilities for the same task. Specifically, in aviation, automation has expanded its areas of expertise with the aim of improving aircraft performance and especially flight safety aspects.

In recent years, several types of automated systems have been developed for use in flight deck [1]. Such applications aim to reduce the crew's workload, make systems more reliable and reduce the number of air crashes by minimizing human error during operation. Despite the efforts that have been expanded, the number of aerial accidents that occur annually still generates significant proportions of fatalities. According to data provided by aeronautical regulatory organizations, three categories of risk are prevalent in air crashes currently [2]: Loss of Control in Flight (LOC-I), Controlled Flight Into Terrain (CFIT) and Runway Safety (RS). Currently, in civil aviation, LOC-I type accidents are low frequency, but on average they account for approximately one-quarter of all fatalities recorded in civil aviation annually.

Automation has generated several positive points about the safety of flight, but it brings with other new problems. As the crew becomes more peripheral to the aircraft's operations [3], the detection of errors becomes more difficult. Along with this, there is a greater oscillation of crew concentration during the operation than the reduction of the manual flight skills. Thus, in an emergency situation, the pilot ends up outside the operational cycle of the system and can act instinctively, instead of following the standardized procedures. Therefore, it is observed the appearance of new errors with the increase of the application of automated systems in aircraft.

2 History

According to the Federal Aviation Administration (FAA), the origin of the human factor, as the cause of aeronautical accidents, began after World War II [4], when the numbers of accidents occurred at that time caused authorities and scholars to look more closely at the human element. A special focus was the cockpit design of aircraft since the bad design of controls and displays often induced pilot errors.

In the early 1980s, pilots were the central information processing units for all flights and the intended purpose of the transition from analogic instruments to electronic flight displays was to reduce pilot workload, trying to make the aircraft piloting safer, easier and more efficient. A new term, CFIT (Controlled Flight Into Terrain) changed the notion of accidents caused by a failure in the man-machine system, especially in the processing of information between them [5]. A human-machine interaction through computers was initially developed within the context of office automation since the mid-1980s. An aeronautical community emerged and it is expanding to other application domains as aircraft automation. In aviation, human factors specialists were interested in safety issues related to automation, and in particular in human errors and reliability.

There was also a conflict of hierarchy, in which often unsafe actions taken by the captain were not questioned, often culminating in an accident. In the future, this factor has been addressed by Corporate Resource Management (CRM).

Since 1990, machines are becoming more and more computerized, and the computers are interface devices between the machine and the operator. Pilots began to complain of being overwhelmed with too much information and little logical flow. The technologies continued to evolve into sophisticated flight management systems, even more gear was added, such as TCAS and EGPWS. Increasing amounts of head-down time during some of the busiest phases of flight brought cries of decreased, not increased, flight safety [6]. It was then that began to consider spatial disorientation, which is the inability to orient correctly in relation to the surface of the earth, as the most important precedent of a CFIT accident.

In 2000, attention has been focused on LOC-I whose definition includes loss of control in flight due to aircraft design, automation, malfunction of its systems, human performance, among other causes. According to the concept, LOC-I is a diversion of the envelope called Upset, that is, a deviation from the normal attitudes of flight.

According to Boeing [7], about 22 loss of control situations in flight that resulted in accidents between 1998 and 2007, with 2051 fatalities. In addition, that there were a large number of incidents in which aircraft were in Upset situations. More recent data from ICAO [2] shows that accidents of LOC-I, CFIT, and Runway Safety risk categories are still responsible for more than ¾ of the fatalities in the world’s commercial flight aviation, as shown in Fig. 1.

Nowadays we are in multifunctional touch flat panels era. Because the new aircraft technology, they have become highly automated and independent of human interventions to fly. Soon, pilots became submissive to the machine, failing to take action in situations in which, through human judgment, they were required. Thanks to this complacency, the only factor that valued flight safety was exclusively the machine.

2.1 Upsets

A diversion of the envelope or a deviation from the normal flight attitudes are called Upset. It can be induced by system abnormalities, pilot or a combination of causes. It is worth emphasizing here the importance of engineering design and pilot training that enables to avoid, and eventually recover, flights in situations that lead to an abnormal flight condition. Upsets

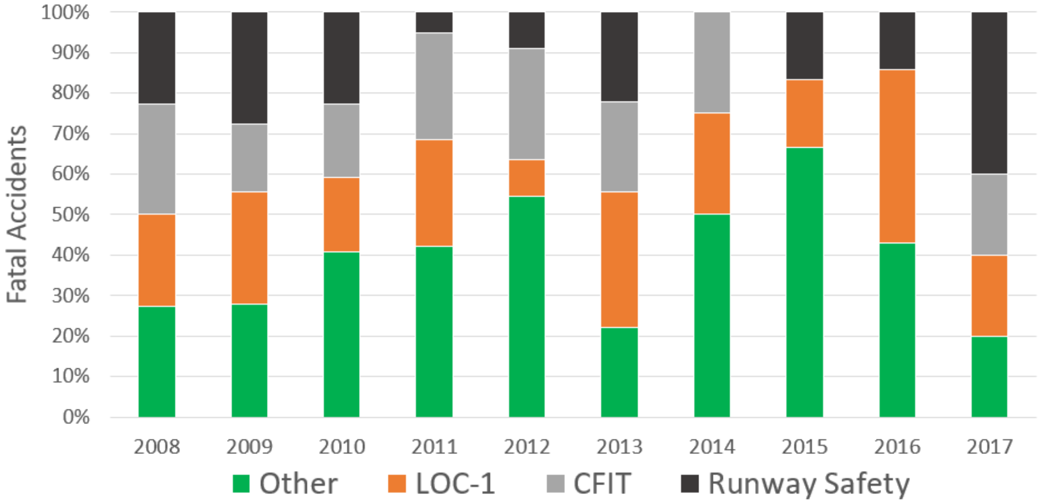

Fig. 1. Share of worldwide fatal accidents by risk category from 2008 through 2017 [2]

induced by the environment like turbulence can lead to a large deviation of speed, altitude or attitude so that the aircraft will be momentarily under abnormal flight conditions.

Currently, even with the great evolution in the ergonomic engineering projects, reliability in the equipment, rigorous homologation process and constant monitoring of the integrity of structures and equipment in search of failures, still occur the system problems and the hard flight conditions. The engineers scrapped the crowded electro-mechanical panels of the past and, using proof-of-concept work done by NASA (National Aeronautics and Space Administration), equipped new airplanes with “glass” cockpits built around flat-panel displays. “The new displays offer many advantages, including the ability to organize the cockpit by consolidating basic flight information onto a few screens, using improved symbols, and burying much of the rest—but in a readily available form” [8]. Therefore, the correct actions needed for each situation must be known and executed, following the philosophy that most failures are surviving. The disorders caused by system abnormalities can be classified as in-flight instrument failures, autonomous flight systems, among others.

2.3 Errors

The use of robotics and mechatronics assisting pilots' decisions and actions would not drastically reduce procedural failures in aircraft piloting. Errors from a systemic and cognitive perspective remain. There is an indication that pilots do not have the training and the continued knowledge of piloting and management techniques to support the modern aircraft. This issue is aggravated by the asynchrony of the processes distributed between computers and pilots, which often generates a lack of knowledge on the part of the pilots of the actions promoted by the computers. Thus, in emergencies, pilots tend to act more by intuition, so standard procedures are not followed or procedures not allowed are performed. Lack of training and disability, considered from different perspectives, are very significant components of accident rates. Poor of training or failure in the cognitive process of initial and continuous learning may be phenomenological or the result of a process originating in health or psychosocial problems.

There were important variations of ergonomic origin causation demonstrated by the items that refer to the training, and information level in the cockpit that increased, paradoxically and substantially with the advent of aircraft automation. Apparently, the knowledge factor is not being treated in the right way, following the great changes in the aircraft cockpit. This study suggests the importance of analyzing this situation in a deeper perspective (The study suggests the existence of a situation in aviation), since incapacitation is a causality that is, in most cases, predictable, monitorable and controllable.

The fails suggest not only training and capacitation but also the need to establish a different format to carry out the process of transferring and maintaining knowledge of flight techniques and aeronautical regulation in the minds of personnel who have a responsibility to keep airplanes flying safely.

The engineering concepts on design automated equipment and relation established between pilot errors due confusing data entry forms, lack of training and less education seek to demonstrate the connections between lack of feedback to engineering staff with the crew reported data. Pilot error is a term used to describe an action or inaction leading to deviation from a pilot intention [9]. It is the major cause of aviation accidents. Due to the modern technology with high-level automation, the pilots are routinely exposed to high amount of complex information processing and cognitive overload. Thus, in a situational stress or emergencies, pilots tend to act more by intuition, so standard procedures are not followed or procedures not allowed are performed inducing an error which may result in a threat to flight safety.

3 Flight 447 Analysis

A typical case of LOC-I occurred in June 2009 with Airbus A330, flight 447, with 216 passengers and 12 crew on board, from Rio de Janeiro to Paris. About 3:45 hours after takeoff, the aircraft hit the water surface with a high nose attitude and high vertical speed. Pitot probes were found to be ice-clogged, with indicated speeds inconsistencies, resulting in the loss of flight control. Soon after the autopilot disconnection, the pilots did not understand the situation and the lack of cooperation between them caused the total loss of cognitive control of the situation. The automatic systems and ECAM (Electronic Centralized Aircraft Monitor) messages, did not help pilots to diagnose the situation. The accident sequence is described in Fig. 2.

The aircraft entered in a pronounced stall and, despite these persistent symptoms, the crew never understood that the aircraft was in this situation and therefore never applied any maneuver for recovery. The pilots applied inappropriate commands destabilizing the flight; According to the final report of the French Research and Analysis Office (BEA – Bureau d'Enquêtes et d'Analyses) in charge of investigations [10], a combination of human error and technical failure, led to the crash of Air France's 447 flight, in the Atlantic Ocean. The BEA reported a sequence of factors that contributed to the crash: first, the incoherence in speeds information, due to the freezing of the pitot sensors, caused the autopilot out. Then the crew did not understand what happened with Airbus and took the wrong attitude, leading to the crash of the aircraft. They had not been trained to act in this situation of loss of speed information and manual piloting at high altitude.

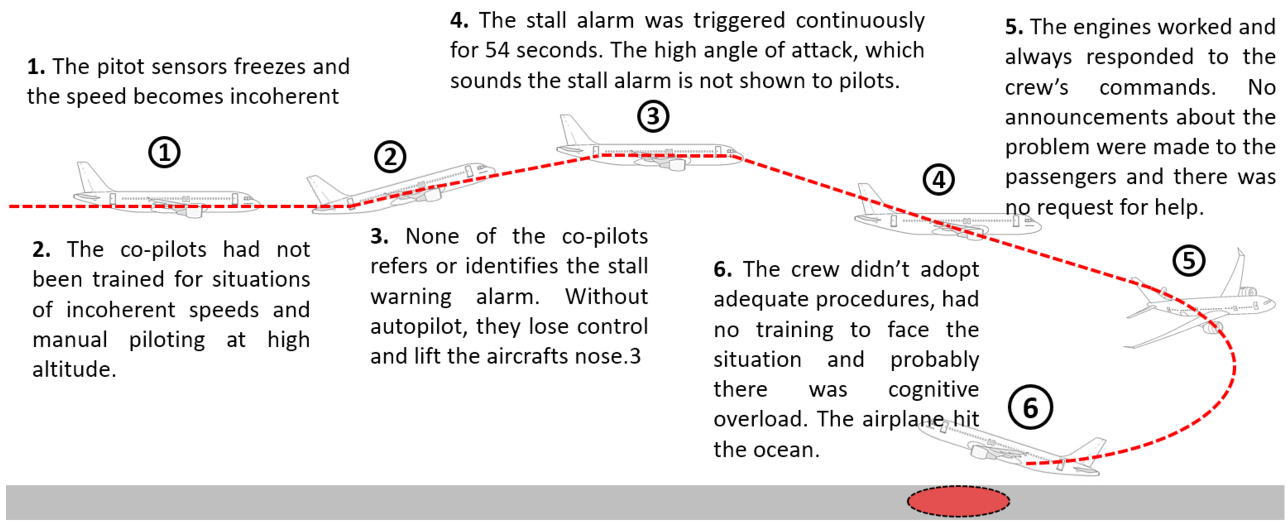

Fig. 2. Air France flight 447 crash sequence

According to BEA final report, pilots may have ignored the stall alarm and not understood that the plane was falling because they believed it would be false signals and the Airbus was in a flight mode with protection against loss of lift.

For the BEA, they may have been confused to understand that the buffet they felt in the cabin during the altitude loss occurred because the plane was very high speed. The determination of the co-pilot to put the airplane's nose up would have been aimed at slowing down.

According to the report, the pilots did not understand that the plane was falling due to wrong speed reading and the lack of visual information of the angle of attack of the aircraft near the stall, which shows a need for improvement in the pilot-automation interface.

With the high reliability of modern aircraft systems, human performance has become a focus area for flight safety. Various types of human errors are often cited as contributing factors to incidents and accidents. We must remember, however, that we are increasingly dependent on complex automation systems and embedded electronics.

The most important point as it applies to Air France 447 is that the very design of the Airbus cockpit, like that of every recent Boeing, is based upon the expectation of clear communication and good teamwork, and if these are lacking, a crisis can quickly turn catastrophic [1].

The investigation concludes that pilot error and technical failures caused the accident. Main human faults pointed out are: The commander went to rest without dividing the tasks between the co-pilots; Although it is continuously fired for 54 s, none of the pilots identify the stall alarm or felt the aircraft's loss of lift, despite persistent symptoms, improperly increasing the angle of attack. The co-pilots had no training for incoherent speeds and manual piloting at high altitude situations.

The main technological failures mentioned were the freezing of the pitot tubes and the autopilot and auto-throttle shutdown; the aircraft was not equipped with a visual indication of alert for the angle of attack, only audible indication. There are no data on the screen ahead of the pilots stating the differences in speed, loss of lift and high angle of attack.

The last indication of the black box showed the climb down speed of about 200 km/h (10,912 fpm). The descent lasted 3min30s. Airbus fell on its belly and nose up: the transcript of the black box states that one of the last sentences of the younger co-pilot was: "We're going to crash! That cannot be true. But what is happening?"

"The A330 is a masterpiece of design, and one of the most foolproof airplanes ever built" [8]. How could an airspeed-indication failure in an uncritical phase of the flight have caused these pilots to get so tangled up? And how could they not have understood that the airplane had stalled? The roots of the problem seem to lie paradoxically in the same cockpit designs that have helped to make the last few generations of airliners extraordinarily safe and easy to fly [8].

Due to the Air France accident, the pitot tubes were replaced on several Airbus models; a number of experts called for angle-of-attack indicators in airliners and urged a new emphasis on high-altitude-stall training, upset recoveries, unusual attitudes, glass cockpit training [8]. The BEA suggested for Airbus "to review the logic of the aircraft control system"[10].

4 Automation error

As long as the pilot flies under IFR (Instrument Flight Rules), the indicators must provide reliable information. For this, constant improvements in quality, design, redundancy, and clarity of the information provided were necessary. However, failures still occur. It is in this situation that the human factor must be inserted, that is, in the face of erroneous information or data divergences between systems, pilots must be able to keep track of the situation and analyze the impact of the problem in order to choose the correct alternative procedure. Many times this does not happen.

Nowadays, in-flight decks, there has been a swift movement to the usage of digital systems instead of mechanical systems. Automation or digital systems can be defined as the accomplishment of a job either in a mechanical or an electrical way [11]. In most of the cases, automation carries out the things, which could be done by humans, decreasing the crew workloads.

Norman [12] shows that engineers are trained to solve problems and he doesn´t understand why they made things difficult to use. He suggested applying psychology to engineering to create more useful things. Designers are trained to discover the real problems. He found that people should be able to comprehend immediately how to use and read simple things and instruments without the need for instructive signs.

Engineering errors occur in a very complicated process because the human being is the most complicated device ever designed and is subject to certain capabilities and limitations. A person may not even realize he has inbound and outbound "filters", allowing just certain types, quantities and qualities of data to be received. He can produce only certain types, quantities, and qualities of output. His identification, interpretation, and choice functions, in particular, are so highly dependent upon training and previous experience, as well as that elusive force, motivation, that errors in the decision process are commonplace [8]

The systems include autopilot, auto-throttle, and any system involved with flight management and guidance. They are extremely accurate systems and gather information from almost all systems. Because of this, pilots now have a high degree of reliability in these instruments, so that excessive automation leads to complacency, masking cases of malfunction, making identification of the source of the problem a complex task. In these cases, the recommendation is precise to reduce the level of automation, that is, to take control of the airplane. This way the pilot will be in closer contact with the fault, which will sometimes help in the search for the anomaly.

4.1 Flight Management System (FMS)

The FMS related accidents number are very high. The FMS help pilots in normal conditions like flight planning, navigation, and performance management. According Dr. Diyar Akay of Gazi University [3] and Joint Aviation Authorities (JAA) [13] approximately 73% of the accidents occur due to Controlled Flight Into Terrain, CFIT, because the modern automation cockpit has “had the effect of making the flight crew more peripheral to the actual operation of the aircraft” [14]. Hard to detect errors, complacency of automation, lack of concentration, difficulty in learning complex systems, confusion, more heads down time, difficulties with communication in changing plans are the other disadvantages of automation [11]. An automation error can occur due to a failure of the system or an incorrect programming of the system done by the user or a false input to the system [6]. Engineers, based on the results of a survey, recommendations were given so as to improve design and usability of FMS.

4.1.1 King Air B-200 Automation Survey

In a survey made with a high automation level airplane, a King Air B-200, Australian and American pilots, the engineers got the following results [3]:

- 62% of the pilots confirmed that due to the last-minute changes that ATC gave, it took a long time to reprogram systems and especially FMS.
- 60% of them believed that automation decreases manual skills.
- 77% of the responders specified that some mode buttons and mode panels were not user-friendly.
- 73% of the pilots had the concern to lose their orientation while FMS programming and selecting mode. And
- 54% of the pilots found some parts of the automation system unreliable.

According to Kathy Abbott, chief scientific and technical adviser for flight deck human factors at the U.S. Federal Aviation Administration (FAA) [15], said in 2010 to Flight Safety Foundation International Air Safety Seminar in Milan, Italy, newer engineering designs should be based on "the flight crew’s ability to understand normal system operations and their ability to function effectively without error, especially when failures occur. (…) The integration of multiple systems should be designed such that the flight crew has clear, definitive and well understand actions in the events of failures or degraded modes" [15].

This statement shows indications of the need for a greater propagation of interdisciplinary knowledge. As Raynaut points out, "The idea of interdisciplinarity converges at times into an intellectual dream: that of restoring the oneness of knowledge; to arrive at new forms of knowledge that embrace and reconcile the multiple faces of knowledge" [16].

The integration of philosophies and policies of human-centered design into flight deck automation are one of the important gaps to be overcome. It is necessary to understand the difference between the philosophy and the engineering design, and the way that the systems are actually operated [15]. For new systems, manufacturers should design flight deck systems more understandable from the flight crew's perspective by including human-centered design processes.

5 Final considerations

The fourth-generation airplanes are now almost half of the global fleet. Since its introduction, the accident rate has plummeted considerably. There are simply no arguments about the success of automation. The engineers behind it are among the greatest unknown heroes of our time. "Still, accidents continue to happen, and many of them are caused by confusion at the interface between the pilot and a semi-robotic machine. The automation complexity comes with side effects that are often not intentional" [8].

"Aircraft accidents are highly visible and often involve loss of life. The pilot error results from physiological limitations inherent in humans. Causes of error include fatigue, workload, and fear as well as cognitive overload, poor communications, imperfect information processing, and flawed decision making". [9]

Over time the automation will expand to handle in-flight failures and emergencies, and as the safety record improves, pilots will gradually be squeezed from the cockpit altogether. There will still be accidents, but at some point, we will have only the machines to blame.

Current work mainly consists of managing highly computerized systems, which leads to supervisory control, delegation, cooperation and coordination of artificial agents' activities. This approach aims to highlight the strong interdisciplinarity exercised by the subject in this investigation. Consequently, a new discipline has emerged, called cognitive engineering. Cognitive models take into account the new evolution of human-machine interaction through computers. It is evolving at the same time as other disciplines such as control theories, artificial intelligence, cognitive psychology, anthropology, and sociology [17].

The current theories on interdisciplinarity aim at integrating disciplines into new approaches, new concepts, premises, and paradigms. It can be emphasized that, in today's more important world, interdisciplinarity has always been present in the learning, knowledge and imagination of humanity and will always be a process of collaboration and dialogue between disciplines, obviously within the limits and reality of each one, making it indispensable for a world permeated by problems of great complexity that challenge contemporary science. The fails suggest not only training and capacitation but also the need to establish a different format to carry out the process of transferring and maintaining knowledge of flight techniques and aeronautical regulation in the minds of personnel who have a responsibility to keep airplanes flying safely. Requirements engineering encompasses both the problem domain of the system as well as the solution domain of the system. The process of establishing the requirements is not an easy task as it is crossing the boundaries of the problem and the solution domain on a regular basis and is bound to have errors.

In any operation that involves the human factor, it must be considered that the error is something that can occur in any type of operation and with any type of professional, such as controllers, pilots, and engineers. Knowing that the best way to mitigate errors and prevent accidents is to train and adjust to the new processes, it is important to be constantly learning and updating, in a proactive way, that is, seeking knowledge at all times in the life of the professional related to the aerial activity. In this way, one learns from mistakes made in the past, so that they are not repeated. It is worth mentioning here a common maxim in aviation and that represents this recommendation: "The more you learn, the more you live."

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