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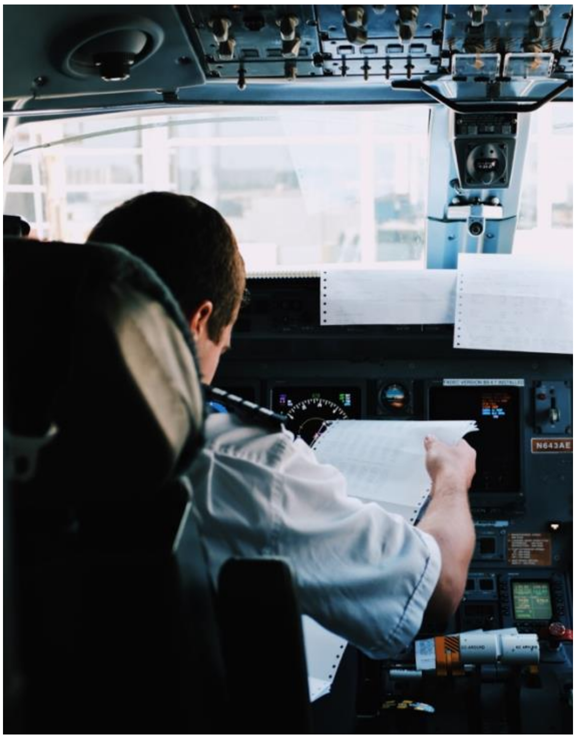

THE PILOT'S PROFESSION ADAPTATION TO NEW TECHNOLOGIES

Since its creation, the pilot's profession for commercial aircraft has not ceased to evolve in accordance with legislation but mainly because of technical progress. As we are right in the middle of the fourth revolution, the profession is again expected to change. This paper aims at providing an overview on what directions the pilot's profession is heading toward and what it involves for commercial aviation.

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Summary

This paper aims at providing a vision of how new technologies will impact the profession of pilot in the next decades in the commercial industry. Indeed, fatal accidents are still occurring and the human factor accounts for the major cause of accidents. Various actors see in new technologies a way to reduce this human risk but also to face issues as the coming shortage of new pilot recruits. There are indubitably economic interests at stake, but we will focus on how new technical progress can increase flight safety and performance. The paper starts with giving a statement on the pilot profession today and why it is necessary to think about its evolution over the coming years. The following part will give an overview on the existing technologies, how they are going to evolve and how the pilot's profession will be impacted. Finally, we will discuss about the issues these new technologies will raise and how they should be implemented to have a positive impact.

Key words:
- Single pilot operations
- Commercial aviation
- Cockpit automation
- Artificial Intelligence
- Human-machine interface and interaction
- Consumer perceptions

Mots-clés :
- Opérations mono-pilotes
- Aviation commerciale
- Automatisation du cockpit
- Intelligence Artificielle
- Interface et interactions homme-machine
- Perceptions du consommateur

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1. INTRODUCTION

1.1 The today pilot's profession

1.1.1 Becoming and being a pilot nowadays

Pilot has always been a fascinating and elitist job. Indeed, many physical, psychological and cognitive assets are required to become a commercial pilot. There are many steps to follow and the competition is ruthless. The objective is to select competent people to do the job as the pilot is responsible of the safety of hundreds of people. Mistakes could be fatal, this is why standards are exacting. The first step is to earn a Private Pilot Licence (PPL). This certificate validates the fundamentals of piloting. In order to become an airline pilot, it is necessary to earn a Commercial Pilot Licence (CPL). The future pilot needs to obtain an instrument rating which would allow him to fly under Instrument Flight Rules (IFR) and in all weather conditions. To do so, he must meet specific experience requirements and fly to a higher standard. To fly large passengers' airliners, pilots must add multi-engine privileges to their CPL (ATP Flight School, 2020).

1.1.2 Current Two-Pilot Operations

There were not always two pilots in the cockpit. Taking advantage of the technological developments of World War II, aircraft manufacturers made the most of the war effort and the first jet aircrafts were introduced: the commercial aviation was born. At the time, five crew members were needed to operate those aircrafts: two pilots, a flight engineer, a radio operator and a navigator. In the 1960's, thanks to technical progress, the navigator and radio operator were no longer needed, resulting in three persons left in the cockpit. Later, aircraft manufacturers made significant improvements particularly in terms of engines (passing from piston engine to jet engine). The flight engineer became then useless, since in-flight troubleshooting was consequently reduced. Boeing researchers, when studying accident factors before introducing the B737, also found that the flight engineers were often a distraction to the pilots because of system problems (Gearhart, 2018). Therefore, in the 1980's, the cockpit consisted of only two members: the Captain and the First Officer (FO). It is now the standard size for commercial passenger flights (Vu, Lachter, Battiste, & Strybel, 2018).

1.1.3 Link between the human and the machine

In the flight deck, the Captain is mostly responsible for the flight operations, and the FO is here to balance the workload and takes over less demanding tasks (McLucas & Leaf, 1981). Because of technological improvements, the role of humans has evolved a long way from basic initial training. Among these new technologies introduced into computer system architectures we can mention digital multiplexing and local area networks (LAN), optoelectronics, massive parallel computing and new neuronal techniques for cognitive engineering (application of cognitive psychology and related disciplines to the design and operation of human–machine systems ; Wilson, Helton, & Wiggins, 2013). But for the moment (at least for now), humans are still superior to machines in terms of level of intelligence and intuition. With the current development of new technologies as artificial intelligence and automation, the AAE (Académie de l'Air de l'Espace) states the gap between humans and machines is rapidly narrowing, impacting the way a commercial aircraft is piloted (AAE, 2018).

1.2 New technologies

1.2.1 Definitions

As said previously, the gap between human and machines is closing. We are currently witnessing the fourth industrial revolution, bringing up new technologies that are blurring the frontiers between the physical, biological and digital spheres. Among these technologies, we can mention artificial intelligence (AI), machine learning, automation, and combination of technologies such as IoT, robotics, big data, augmented reality, 3D printing… (Bloem, et al., 2014). With this new revolution, machines will no longer surpass humans in terms of physical strength, but also in terms of cognitive capacities in certain domains, which can be concerning and troubling for us, human beings (Wang & Siau, 2019). For that matter, a Pew Research Center study stated that 63% of participants think that AI will make us wealthier, but it will negatively impact our society (Mack, 2018).

Artificial Intelligence refers to an "umbrella concept that influences and is influenced by many disciplines, such as computer science, engineering, biology, psychology, mathematics, statistics, logic, philosophy, business and linguistics" (Buchanan, 2005; Kumar, Kharkwal, Kohli, & Choudhary, 2016). Two types of AI exist: weak AI (excels in specific tasks; it is the most common type of AI) and strong AI (processes multiple tasks proficiently). Transhumanists believe a strong AI can develop its own conscience and become the equivalent of a human being in terms of intelligence. According to Bostrom (2014), the advent of strong AI will generate an "intelligent explosion" and AI will turn into a "super intelligence": AI will transform into a virtual intellect capable of exceeding the human cognitive performances in every domain of interest (Wang & Siau, 2019).

Automation is a system or a technology automating a task previously executed by the human and follows pre-programmed rules (Wang & Siau, 2019). The role of automation is to replace functions previously performed by humans or provide cognitive support for human operators (Parasuraman, Sheridan, & Wickens, 2008). In this way, automation frees humans from time-consuming and repetitive tasks (both physical and cognitive tasks).

Samuel (2000) defines **machine-learning** as a field of study enabling computers to learn without being explicitly programmed. In other terms, machine-learning is an automated process enabling machines to analyse important volumes of data, to recognize patterns and to help making predictions or decision-making from the data collected (Wang & Siau, 2019). This technology is thereby based on feedback. Moreover, machine-learning can be perceived as the automation of cognitive functions (Parasuraman & Riley, 1997).

Robotics are technologies used to develop machines, called "robots", capable of imitating human actions. There is no necessary physical resemblance with human beings, but it allows them to be more accepted in our society. Artificial intelligent robots are expected to be able to learn by themselves and to surpass humans (Wang & Siau, 2019). This time Parasuraman and Riley (1997) refer to robotics as the automation of physical functions and directed by machine-learning.

In this paper we will particularly insist on automation and AI, for they are the most technologies discussed in recent researches on pilot's profession evolution.

1.2.2 Promises and benefits

Applications of these new technologies can create substantial benefits for the society. They have an important potential in various fields such as business (HR for instance), healthcare, education, military, cybersecurity, finance… Today many innovations are based on AI, of which autonomous car or facial recognition.

AI and automation, especially, can be implemented in manufacturing. AI has already been of benefit to the manufacturing industry by providing real-time maintenance of equipment or virtual design. According to Insights teams (2018), thanks to AI and automation it is possible to complete 50,000 days of engineering in one day. This is mostly feasible because with AI, one can input specific goals in a software design; the software will explore all possibilities and after many trials, it will be able to find different solutions and create design alternatives, as well as being able to enable their testing and their feasibility (Wang & Siau, 2019).

Concerning automation, since it is a technology capable of selecting data, transforming information, making decision and/or controlling processes (Parasuraman & Riley, Humans and automation: Use, misuse, disuse, abuse, 1997), its goal it is relieve human from certain tasks. Thus, automation can increase performance, accuracy, reliability and efficiency (Hughes, Rice, Trafimow, & Clayton, 2009). In the context of civil aviation, research in automation went towards precise objectives: automated systems have to contribute to safety and crisis management (AAE, 2018).

1.3 Importance, interest and necessity of the topic

1.3.1 Factors explaining fatal accidents

Recent decades have been marked with a decrease in the number of fatal accidents in aviation, but today their number are stabilizing, and due to the traffic growth of commercial flights, the AAE stated that the accident rate will have to be cut by four worldwide if we want to avoid an increase in the absolute number of accidents (AAE, 2018). Thus, AAE advised international organisations as the ICAO, EASA or FAA to set goals and work on different factors playing a role in fatal accidents.

Among these factors, even with the development of autopilots, the human factor accounts for 51% of causes of accidents, far ahead from factors as the environment, the aircraft composition or the engines (AAE, 2018). Today, pilots are solicited for various technical and computer tasks, and a bad decision or interpretation can quickly lead to an accident. Those mistakes can be linked to the pilot's behaviour (stress, tiredness, etc.) but also to an inappropriate reaction facing an unforeseen event, an error of judgement, the non-respect of processes…

1.3.2 Human limits of the pilot

As the human nature, pilots have limits that could be hazardous concerning the flight safety. Regarding the past half century, statistics show that air accidents due to technical factors have reduced considerably, while the human factor has increased (cf. Appendix 1). Most of the human originated accidents are involuntary but a few aren't. After the Germanwings 9525 crash in 2015, mental health issues have become a preoccupation and a study has been made to analyse depression and suicide risks among commercial pilots. With over 1,800 pilots asked, 12.6% of them have shown depression symptoms and 4.1% of them have had suicidal thoughts in the 15 previous days. This study revealed that pilots don’t talk about their mental health as they fear for their carrier, and demonstrated the importance of a psychological support in the airlines (Wu, et al., 2016).

We can define the human reliability as the human competence for the fulfilment of a special duty in a fixed framework for an accepted period. These competences include physical and psychological abilities together with necessary experiences and skills and moral and characteristics peculiarities. This ability to fulfil the duties in diverse conditions is a function of various factors called Performance Shaping Factors. Among them, we can find the available work time, the time required for doing the job, the stress causing factors, the personal and group experience, the controlling means, the reflection of operation, the work process documentation, the equipment arrangement, the social factors, the physical factors and the interdependency of job with each other (cf. Appendix 2). This cumulation of factors demonstrate the difficulty for humans to avoid mistakes, so the human limits.

Finally, in order to fix and improve the human reliability, some ideas have been developed. Professor Edward made a model, the SHEL model, where he put the human factor as the key and pivotal factor interacting with other factors (machine, environment, etc. ; cf. Appendix 3). Researchers have done various classifications to identify human errors such as the structural and fundamental classification used for evaluation of human capabilities (What? When? How? Where?) or the statistical grouping which consists to classify manner, form and frequency of errors. Faber (1994) proposed a three-phase process which needs to be continuously revised to match the new situations. This process consists in selecting the proper personnel through testing, then organizing the connecting points of personnel with equipment through uniformity of technology with human peculiarity and finally, improving and modifying the personnel technical, psychological and physical capabilities via training (cf. Appendix 4 ; Afrazeh & Bartsch, 2007).

1.3.3 Increase of traffic growth and economic reasons

According to NASA and FAA, air vehicles operations are expected to double or triple by 2025. To support this increase in traffic growth, more pilots will be needed to operate aircrafts. However, the today’s commercial aviation has difficulties finding new pilots and is expected to face a shortage in new recruits. New FAA regulations also require an increased flight experiences for new recruits and an increased duration of rest between flight for every pilot (Carey, Nicas, & Pasztor, 2012). To handle this growth and these new rules, actors like NASA are currently developing NextGen operations, that is to say technologies relying less on pilots, which also means a shift in pilots’ responsibilities. To face these new responsibilities in the flight deck, it is likely that more automation will be needed, especially in terms of design (Sebok, et al., 2012).

Additionally, today, pilots accounts for the highest category of direct operating expenses (25%) for airlines (Norman, 2007). Reducing onboard flight crew will enable cost savings because of these direct expenditures, but also because it will generate savings from crew scheduling.

2. THE EMERGENCE OF NEW TECHNOLOGIES IN THE PILOT'S PROFESSION

2.1 Explanation of existing tools

2.1.1 An overall automated system: the Flight Management System

The Flight Management System (FMS) is the primary autoflight system on current flight deck. It is a high-level automation for flight path control: its first aim is to help the flight crew create a flight planning (creation, revisions, predictions, secondary flight plans and time of arrival). It consists in a Control Display Unit (CDU) and a computer. This technology was previously expensive and implemented in military aircraft, but it is found today on most civil aircrafts. This is especially thanks to the FMS that there is no more flight engineers nor navigators onboard today, since this automated system has considerably reduced the workload of flying crew. One essential function of the FMS is navigation, using databases containing location of waypoints or airways, radio navigation aids, airports data, runways, standard instrument departure, instrument approach procedures… Navigation data are used by the pilot(s) to build flight plans ; once the flight plan established, it is sent for display to the Electronic flight instrument system. The FMS is also used for exact position determination using a group of sensors placed on the aircraft. Once knowing the flight plan and the exact position of the aircraft, the FMS is capable of calculating the optimal route to follow (Ramsurrun, 2018).

The FMS is also used for other purposes: prediction and optimisation of performance, fuel management, landing system (FLS), aid for diversion, takeoff securing (TOS), takeoff monitoring (TOM)… (Airbus, 2011).

Thereby, the use of the FMS has contributed to increase flight crew performance, especially in preparation of critical events such as an approach revision (Chen & Pritchett, 2001 ; Wright, Kaber, & Endsley, 2003). Yet, high-level automation also signifies a drawback in terms of pilot situation awareness and performance in dealing with such events, because the pilot is no longer deeply engaged in aircraft control loops.

2.1.2 Precise examples of automation: autopilot and autothrust

As said previously, the FMS is the overall system that manages autoflight. Among the tools it supervised, we can mention the autopilot and the autothrust.

The autopilot is in charge of controlling the trajectory of the aircraft. The autopilot does not replace humans: it assists the flight crew by taking over some tasks previously done by pilots. This system uses a computer software to control the aircraft. Using flight parameters and aircraft's current position, it guides the aircraft with a flight control system (three axes of control: roll, pitch and yaw). The first aim of an autopilot was to maintain heading, speed and altitude. Now, modern autopilots are able to land aircraft on its own through aided landing (Ramsurrun, 2018). According to the ICAO, aircrafts with more than twenty seats should be equipped with an autopilot system.

Autothrust (or autothrottle, A/THR) is used in conjunction with the autopilot. Instead of controlling the fuel flow manually, pilots use autothrust to control the power setting of an aircraft's engines by entering a desired flight characteristic. It calculates the right amount of fuel needed for reaching a targeted air speed, or a speed adapted to specific phases of flight (takeoff, climb, cruise, descent, approach, landing and go-around). Autothrust thus decrease pilots' workload, help better manage fuel consumption and engine condition, and ensures protection against excessive angle-of-attack (Airbus, 2011).

2.1.3 Other embedded systems

Other useful tools can be found around the pilots, even if not automated.
The Head Up Display (HUD) consists of a projector unit, a combiner and a video generation computer. Its transparent display enables the pilot to keep viewing his/her environment while flying without looking in the cabin, which is useful for navigation and landing. It is more used for military aircrafts, but it can also be found in commercial aircrafts, especially modern ones as the A350.

The Enhanced Vision System (EVS) supports pilots in seeing invisible obstacles especially at night. It uses infrared and radar technology and is useful for landing, takeoff and taxiing when in poor visibility. This tool is generally associated to HUD.

The Ground Proximity Warning System (GPWS) is an alarm alerting pilots in case the aircraft is in immediate danger through a radar altimeter determining the aircraft height above the ground (naturally the GPWS only works when the aircraft is not in landing configuration).

The Traffic Collision and Avoidance System (TCAS) prevents air collision in mid-air using a secondary surveillance radar transponder. It is helpful in uncontrolled areas. ICAO requires every aircraft heavier than 5700 kg to be equipped with a TCAS system (Ramsurrun, 2018).

2.2 Theoretical papers used to evaluate changes in the pilot profession

Because of reasons explained above, today's airlines, aviation industry but also public organisations understood the needs to make evolve the profession of the pilot.

As seen in the introduction, the flight deck configuration has evolved from five crew members to two crew members, talking today of "two-crew operations" (TCO). Now the recent trend in commercial aviation is to move from this TCO to SPO: single-pilot operations, expecting to considerably impact the pilots' work environment and tasks (Faulhaber, 2018).

Two concepts of operations for SPO have been brought to light (Vu, Lachter, Battiste, & Strybel, 2018). On one hand, ground-based operational concept: an onboard pilot is supported by a ground operator provided aid for in-flight-critical operations. On the other hand, cockpit-based technologies, capable of performing tasks in order to decrease the overall workload (Comerford, et al., 2013).

2.2.1 Single-pilot operations: an onboard pilot assisted by a ground operator

In its paper researching future models in commercial aviation by 2050, the AAE introduces SPO as a single pilot in the flight deck supported by a ground pilot. While the onboard pilot supervises the flight control, the ground pilot should procure him continuous assistance in specific flight stages (takeoff, initial climb, final approach, landing), and non-continuous assistance during other phases of flight. A ground operator should be assigned between five and eight flights simultaneously, while also counselling to always keep in mind reaching the best compromise between safety and operational efficiency (AAE, 2018).

For Vu, Lachter, Battiste, & Strybel (2018), SPO signifies that the FO is located remotely and acting as the ground operator, while supporting the Captain (the onboard pilot) when requested. The FO should be able to shift between two modes: from supporting routine tasks to providing extensive support. A study was run to reveal the effects of separating the FO and the Captain: no impact was found on subjective workload and decision-making, even if the participants admitted they preferred face-to-face interactions. Nevertheless, communications between pilots were negatively impacted because of lack of non-verbal cues and actions (Lachter, et al., 2014).

Another research mentions that the ground operator could be assisted himself by an on-board Virtual Pilot Assistant (VPA). Indeed, after studying human factors engineering (application of psychological and physiological principles to the engineering and design of products, processes, and systems ; Wickens, Lee, & Liu, 2004), system designs aspects of conventional TCO aircrafts as well as RPAS (Remotely Piloted Aircraft Systems), a concept of VPA was established. This system would be able to perform a real-time assessment of the single-pilot's cognitive states and, based on the predictions of the performance level of the single-pilot, it could alert the ground operator when the situation is deteriorated and the single-pilot can no longer operates the aircraft. In this case, the VPA enables the aircraft to operate as an RPAS: the ground pilot takes over and proceed to the emergency landing (Lim, Gardi, Ramasamy, & Sabatini, 2017).

2.2.2 Single-pilot operation: cockpit-based technologies

When not relying on a second human operator, we talk about cockpit-based operation concepts. It means that automation needs to be extended on the flight deck in order for the single pilot to operate the aircraft without the assistance of a ground pilot (Vu, Lachter, Battiste, & Strybel, 2018).

In his research paper Ramsurrun (2018) introduced a concept of Virtual Assistant (VA). It would consist of a system integrated in the cockpit that associates existing technologies (e.g. Chatbot, FNRIS - Functional Near Infrared Spectroscopy, AI, Eye tracker, Aero Glass…) to assist the single-pilot. The VA would then take over the role of the co-pilot. In order to function, the VA should have continuous access to flight parameters (speed, altitude, power, heading…). By collecting these data, the VA would be able to propose an optimal route, manage airspaces, guide the single pilot when landing… When an issue occurs, the VA notifies the pilot (today it is done through alarms and sensors) and resolves the issue if the system has enough maturity, meaning if the system can use AI. The VA could also be used to ensure law and regulation consideration. By using FNRIS (a technology measuring brain activity to detect the pilot's tiredness), eye tracker (detects abnormal behaviour by measuring eye movement) or heart rate watch, the VA could assist the single pilot in case of anomaly.

Subsequently, a study thought of another concept of interface for SPO. The concept is defined as the Cognitive Pilot-Aircraft Interface (CPAI). It would be armed with adaptive knowledge-based system functionalities. By detecting in real-time pilot's physiological and cognitive states, the CPAI allows to avoid pilot's errors and promotes synergies between the human and the avionics systems. It would support essentially the single pilot in safety-critical tasks (Liu, Gardi, Ramasamy, Lim, & Sabatini, 2016).

2.2.3 The human and the machine: a crew as a whole

As a result, the human and the machine will no longer be two autonomous entities of the flight deck, but rather a new team working closely together.

The notion of Human-Autonomy Teaming (HAT) has been developed and is defined as the way automation and human operators work together to solve problems. The automation is considered as a team member (Vu, Lachter, Battiste, & Strybel, 2018). A tool called Autonomous Constrained Flight Planner (ACFP) can be used to evaluate the HAT. It brings up the checklist, integrates information and keep up with important tasks and workload without any change in pilots' decision-making time nor their levels of situation awareness. For now, ACFP is still a prototype and needs further research (Matessa, et al., 2018).

Moreover, researchers have imagined a whole system where most of the interactions on the flight deck are between a human and a written software. They named this kind of interaction Human Machine Teaming (HMT). To get a successful HMT, some key ergonomic elements should be developed such as facility of learning and remembering key functions, efficiency and intuitiveness of using automated functions and reduction of pilot-induced errors. In this kind of system, the AI would need to learn, communicate and correct deviations, much like that of a second crewmember. We could consider four major systems including communications, surveillance, flight management and Human-Machine Interface (HMI). In this concept, HMI is the more important, utilized as a cognitive human-machine interface. One of the functions should be to evaluate pilot workload management, stress levels, fatigue and incapacitation. To do that, HMI should incorporate psychophysiological sensors which monitors pilot vitals in real time, meaning the pilot would be physically wired to the machine. Finally, the AI should move to adaptive learning, so changes could be made depending the evaluation of pilot's vitals (cf. Appendix 5). If the pilot is fully incapable to perform his tasks, there would be a transfer of tasks to the machine or to the ground crew (Gearhart, 2018).

3. FUTURE ISSUES AND CONDITIONS

We have seen above the current state of cockpit automation and how new technologies are possibly going to redefine the pilot's profession, passing from TCO to SPO. But as every progress, technological improvements come with pitfalls. One major problem for automation, for example, is that it rightly reduces workload but also leads to issues of vigilance (Warm, Matthews, & Finomore, 2017) and decreases pilot situation awareness. It is therefore necessary to think about how to mitigate these pitfalls (Vu, Lachter, Battiste, & Strybel, 2018).

3.1 Conditions to use these new technologies

3.1.1 Find the right balance between human and machine

As mentioned earlier, the human and the machine are expected to form a crew as a whole. Because of mutual exchanges between them, it is important to think about how they interact. The objective, for a healthy interaction, is to create a symbiosis between the human and the technology. In this way, it is needed to generate a machine solicitous of its user, because the error rate is drastically reduced when the human joins forces with the machine (whereas the error rate increases when working separately ; Wang & Siau, 2019).

The previous point is also highlighted in the conditions needed to ensure the well-functioning of HAT, that places automation as a team member of the flight crew. The authors insist on the fact that the human has to have a deep understanding on the functioning of the automated system. In return, preferences, attitudes and states of the pilot have to be well understood by the automation. The promoters of HAT also require fast and bidirectional communication between the human and the system. Lastly, the human must always be the one setting the goal and priorities, not the machine (Vu, Lachter, Battiste, & Strybel, 2018).

As for AAE researchers, if we want to ensure a good relationship between the human and machine within the flight control loop, it is primordial to set priorities for the automated system. In this way, one of these priorities is to develop the preventive role of automation over its remedial role. Instead of wanting immediately to build complex automated system, we should start by building minimal but reliable systems. Only on these conditions automation will contribute to sane interactions between human and machine, safety and crisis management (AAE, 2018).

3.1.2 Technical challenges

Generally speaking, development of previously mentioned new technologies will have to cope with technical challenges. In order to implement them, it will be necessary, for example, to increase the computing power, to ensure the continuity of learning so the technology keeps adapting to an ever changing environment with unforeseen situations, to develop complementary technologies (IoT, reinforcement learning…), to create algorithms capable of eliminating bias… (Wang & Siau, 2019).

Implementation of SPO faces some technical challenges, but there are not insurmountable. The AAE emphasises on the need, in the future, to build complex software: because of the numerous interconnexions enabling automation, it will be more and more difficult to watch over the combinations of possible cases. Thus, improvement in terms of systems are necessary in order to avoid unforeseeable knock-effects (AAE, 2018). Progress in terms of design are also required in such a way that automation keeps reducing workload while maintaining the pilot's vigilance and awareness. To do so, automated systems will have to be capable of processing natural language, to know intuitively when to take over from the pilot in accordance with the context, to perform independent monitoring of aircraft state, to indicate through verbal and visual indicators when it is performing a task, and to be able to self-diagnose in case of any issue (Vu, Lachter, Battiste, & Strybel, 2018).

3.2 Recommendations and impacts on the ecosystem around the pilot

3.2.1 Acquire the consumer support

New technologies will only thrive if accepted by society. Without trust, their adoption is threatened (Siau & Shen, 2003), mostly because systems such AI or automation are seen as a "black box" difficult to understand, therefore difficult to trust. Already known risks linked to new technologies (bias, autonomous cars accidents…) maintain concerns towards them. People are keeping up the idea that new technologies are going to surpass humans: not only it means they could control us, but also that mankind would no longer be the most intelligent being in the world… (Wang & Siau, 2019).

Accordingly, studies were conducted to compare attitudes towards human pilots and automated pilots. It was found that participants rated more favourably a human pilot than an automated pilot. Indeed, participants, that are consumers, felt better towards human pilots: they trusted them more, had more confidence in them and believed they were more capable of handling emergency situations. Nonetheless, the studies also shown that there were ways to improve consumers' feeling towards an auto-pilot: by inducing a positive affect towards automated pilots and by increasing the perceived quality of automation, it is possible to convince the concerned consumers that automated systems are a positive progress (Hughes, Rice, Trafimow, & Clayton, 2009).

3.2.2 New ways of training

As human and machine will certainly become indissociable and form the next flight crew, pilots and new recruits will not be trained the same way as they are today. A redefinition of competences is necessary for each individual (pilots, engineers, maintenance agents…) as well as their functions. With the automated system in charge of the flight envelope, the single pilot is left with the tasks of monitoring the situation (and take back control if necessary). Thereby, pilot training is foreseen to pass from a knowledge-based to a skill-based learning, which also has to be integrated in the pilot selection process. It is necessary to start thinking about new ways of training now, even if the true challenge concerns the pilots: they will be the ones to acquire new abilities, particularly understanding how the system works and reacts (AAE, 2018).

A part of this redefinition is to think about new ways to train pilots in simulators, since it is through aircraft simulators pilots acquire and renew their flight license. Gil, Kaber, & Kim (2012) advise simulators' manufacturers to build the future motion-based simulators more faithful to reality by promoting realism of scenarios for pilots, increasing the sense of urgency in the reroute decision, and working on reducing pilot TTC (Time To Completion, includes decision phase time and implementation phase time).

3.2.3 Create a new environment to induce new technologies development

An indubitable parameter to ensure the implementation of new technologies in our society is to create a rightful environment for their development and application.

One main issue is to quickly settle legal issues and create regulation policies. There is a common agreement on this matter but only a few know what laws should be written. For now, some countries have started creating a legal frame for new technologies development (especially IA), of which France, the United Kingdom, or the European Union (Wang & Siau, 2019). To move more rapidly on this matter, the AAE thinks the drone industry could inspire the commercial aviation's law makers: given that RPAS and single-pilot operated aircraft have similitudes, the drone sector provides an ideal basis for pre-development of automated systems. Gradually, the drone industry and the commercial aviation industrial will join forces and development together a legal frame (AAE, 2018).

On another hand, even if many initiatives are being led by the aviation industry, States and private research organisations, one organisation should take the lead and gather all these players in order to be more efficient and create synergies between them. It would also be in charge of bringing closer aeronautics players with other fields of application (such as the automotive industry).

3.2.4 The air transport environment will need to adapt as well

The development and implementation of SPO will not only affect the pilot's profession, but all actors involved in commercial aviation will be impacted as well. Naturally, airlines will have to redefine flight crew configuration and schedule. Since only one pilot is in the cockpit, airlines will have to make sure the pilot is in good mental and physical condition to operate the aircraft. They will also have to clarify who, of the flight attendants and the ground operator, will take over the single pilot if necessary (in case of pilot incapacitation for instance) and what are their new responsibilities. It of course involves creating a brand new profession, the ground pilot, and think about his/her functions (What is his/her training? Does s/he only operate from the ground or does s/he alternate from air to ground?). It entails as well to be sure that the ground pilot is part of the OCC (Operations Control Centres, in charge of coordinating and monitoring airlines' flight schedules) since it is only through these centres that pilots and airlines are in contact ; the ground pilot will have to be included in these exchanges.

Additionally, SPO will impact other areas, such as Air Traffic Management (not its functions, but more trajectories and improving collaborative decision-making by gathering information between players), Communications (more automated aircrafts require more secured communications) or Aviation meteorology (better knowledge on weather conditions is vital for flight planning ; AAE, 2018).

3.3 Technologies will still need humans onboard

3.3.1 Keep the pilot in the loop

As mentioned previously, automated systems require algorithms, but the latter are compared to black boxes whose functioning is not fully understood. On the contrary of software whose predictability is known, meaning the software will do what it was created for without added anything mischievous, (Paravastu, Gefen, & Creason, 2014), the black box of algorithms prevent this predictability. So, it is needed to work on the transparency of the system and perfectly know when the human enters in the decision-making process. The more the machine is intelligent, the higher the risk (Wang & Siau, 2019).

There is a consensus in commercial aviation and SPO concepts that, at least for now, the pilot should always be part of the aircraft control loop. As mentioned earlier, high-level cockpit automation implicates a reduced workload but can also lead to a lower pilot situation awareness. It is true that loss of control can be due to this loss of situation awareness but it is also due to pilot "out-of-the-loop" performance problems. This is why it is important, even with greater cockpit automation, that the pilot remains in the flight control loop, allowing superior pilot situation awareness to deal with unforeseeable events, like a re-route revision (Gil, Kaber, & Kim, 2012).

Keeping the pilot in the loop is also following on from pilots' desires and interest in their profession. Pilots do not consider automation negatively, but it is important to them to remain managers of these complex systems and not "button pushers" who act passively (Weyer, 2016).

3.3.2 Guarantee cognitive functions and redistribute workload

Since in SPO the human and the machine form a new flight crew, it is needed to think on how to redistribute tasks between them and how to replicate the previous relationship between FO and Captain. Given that the machine is replacing the co-pilot, it is necessary that it takes over not only technical aspects, but also other procedures and duties such as relieving the single pilot from boredom or stress management (Vu, Lachter, Battiste, & Strybel, 2018).

Same applies for cognitive functions. With technical progress and the advent of TCO, flight crew workload came down to cognitive process instead of physical flying activities. Moving to SPO, these cognitive functions should once again be redistributed. A study was conducted to research on how this new redistribution was going to happen. It was found that even without another pilot to monitor flight deck systems, the cognitive workload of the single pilot was not considerably higher for SPO than for TCO. Participants of the study even said they were on higher alert and more attentive when flying in SPO conditions than TCO. Cognitive functions are thus still guaranteed because better prepared to handle the workload on their own (Faulhaber, 2018).

In the case of SPO with a ground operator, tasks and workload need also to be redistributed. Even if separate the Captain and the FO has no impact on their workload, the communication between them was deteriorated because of non-verbal cues and actions (Lachter, et al., 2014). Thereby, in order to keep good awareness and good crew resource management (CRM promotes the use of non-technical skills to ensure the safety of the flight), it is vital that these non-verbal communication skills are maintained in SPO (through CRM tools as tasks dispatching for instance). Additionally, it is to the single pilot to perform tasks requiring high workload; the ground operator only performs tasks associated with low workload, but he can extend his support when necessary (e.g.: pilot incapacitation ; Vu, Lachter, Battiste, & Strybel, 2018).

3.3.3 Having no humans onboard is not realistic before 2050 in terms of safety

Automated aviation is a challenge for the aerospace industry but will require more technological maturity to become fully operational. Therefore, it's not realistic before 2050 in terms of safety. Pilots are still irreplaceable for managing the thousand mishaps and incidents encountered during each flight which could degenerate into catastrophe. Systems designers cannot anticipate unforeseen events as it is impossible to implement this in-flight control software system so only pilots can face them. Autonomy will only be possible to certain conditions but there will be a need for complementary human assistance on the ground as a degree of aircraft autonomy in certain circumstance in order to ensure an acceptable accident rate (AAE, 2018).

Moreover, we can easily identify the limits of AI. Indeed, the machine could hardly replace the human in terms of emotions and the lack of empathy could be problematic in the crew cooperation. In the case where AI could analyse the pilot's vital information's, there it would be necessary to answer some questions. As vital conditions depend on a human different to another, there would be a risk for bad interpretation from the AI and bad decision-making consequently. On top of that, would the pilot agree to give its personal data to the machine? What would happen if he refuses? A proportion of pilots wouldn't like to have software probes onto their body. Regarding the interactions with the ground crew, we can clearly determine some issues too. There could be authority conflicts, willingness of control and difficulties to trust. Also, as the ground crew can take control of the aircraft by datalink software, hackers could do it too so there would be a huge need of cybersecurity. Finally, if the pilot supervises and the machine operates, the pilot would feel to be just along for the ride to "chaperone" the system. Indeed, for safety reasons, he couldn't deactivate the system to take the control. Consequently, the pilot job would be less attractive due to the lack of responsibility. A potential solution would be the automation degradation, meaning the reduction in the amount of automation authority used to control the flight. This kind of solution could be interesting as the machine lacks judgment and the pilot can recognize a situation that the computer does not. For now, pilots with autonomous judgement and empathy can better analyse and correct nonstandard situations that occur in-flight (Gearhart, 2018).

CONCLUSION

Moving from five crew members initially to two-crew operations nowadays, single-pilot operations seem the best way to face the coming shortage in pilots, reduce airlines expenses and decrease the number of fatal accidents.

Different concepts of SPO are currently introduced, from ground-based to cockpit-based operations concepts. None seems better than the other, but it is most likely that no major challenges will prevent them to become, soon, a reality. As a matter of fact, on December 18th, 2019, Airbus has successfully demonstrated the first fully automatic vision-based take-off on its A350-1000 during a test at Toulouse-Blagnac Airport in France (Airbus, 2020). This is only the beginning, and the expansion of advanced automated systems and tools will need further developments. Research in human factors and certification will also have to be conducted. Human incapacitation is not likely to happen, but procedures handling this situation need to be researched as well as if the system will be capable of managing every possible scenario.

SPO and new advanced autonomous tools are not negatively perceived by pilots, as long as they remain managers of the system and are well trained to operate an aircraft with these new technologies. Nonetheless, SPO involves the pilot to be left alone with no other human presence in the cockpit: thinking about impacts on social, interpersonal and motivational aspects is also needed. On the other hand, the social impact of having only one pilot on the flight deck is a major topic to handle: preparing consumers to SPO is primordial.

If we talk about single pilot operations over the coming years, having zero pilot in the cockpit is not (yet?) realistic. First because on the technical point of view, the human is still needed in the cockpit; and secondly, it is not recommended in terms of safety. But passengers better prepare themselves, one day, to fly in remotely operated aircrafts…

APPENDIX

Appendix 1

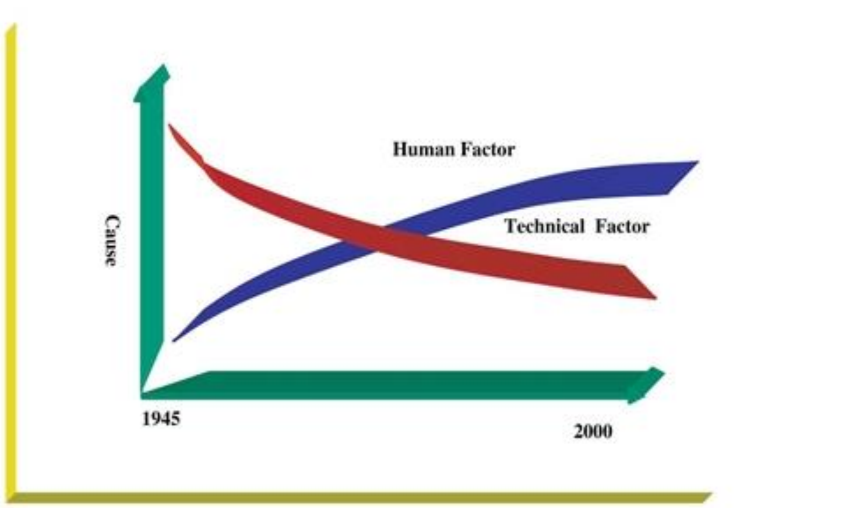

Figure 1 - The trend of air accidents on the biases of Technical-Human factor (Afrazeh & Bartsch, 2007)

Appendix 2

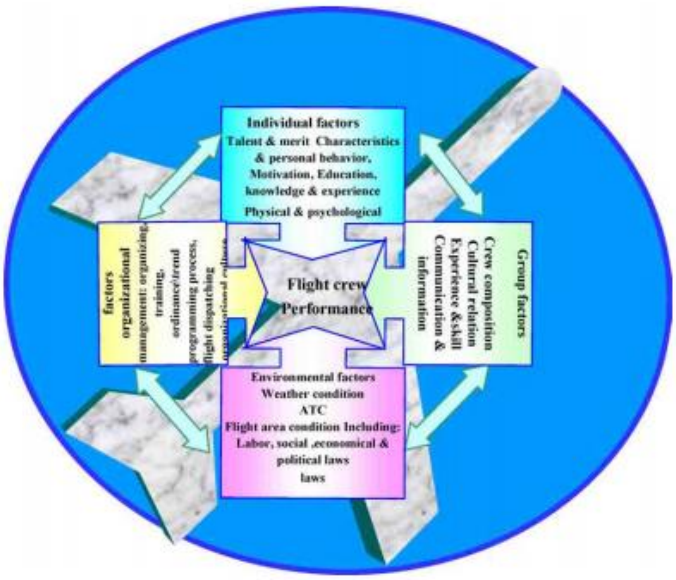

Figure 2 - Factors effecting crew performance (Afrazeh & Bartsch, 2007)

Appendix 3

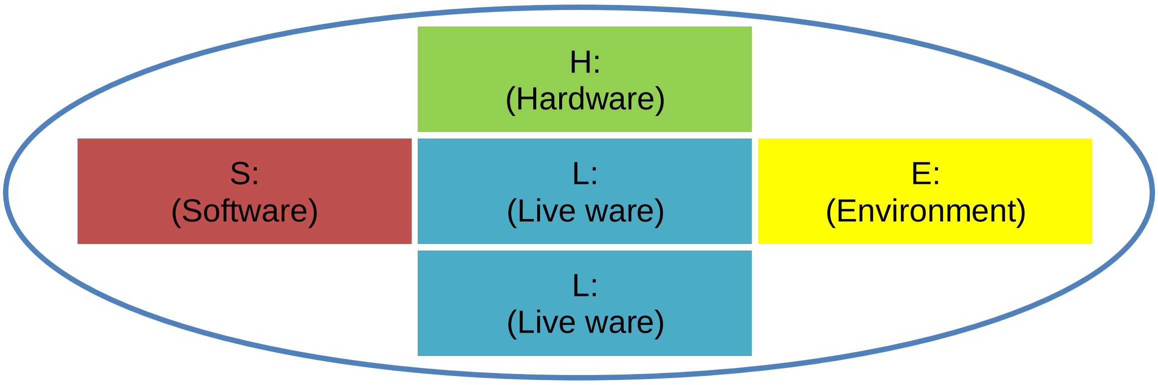

Figure 3 - Illustration of SHEL model (Afrazeh & Bartsch, 2007)

Appendix 4

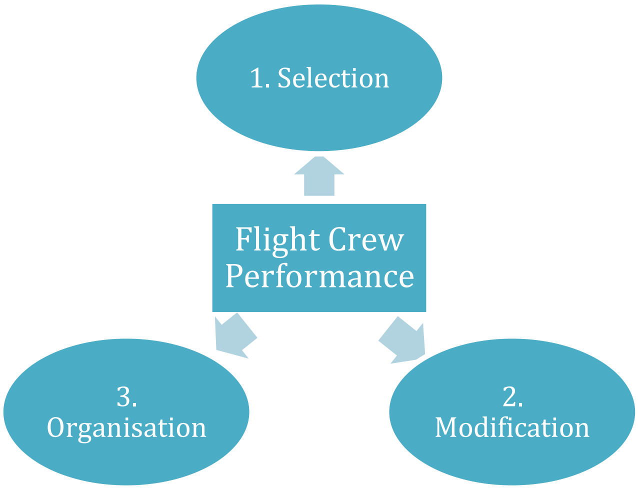

Figure 3 - Dynamic process of improving performance of crew (Afrazeh & Bartsch, 2007)

Appendix 5

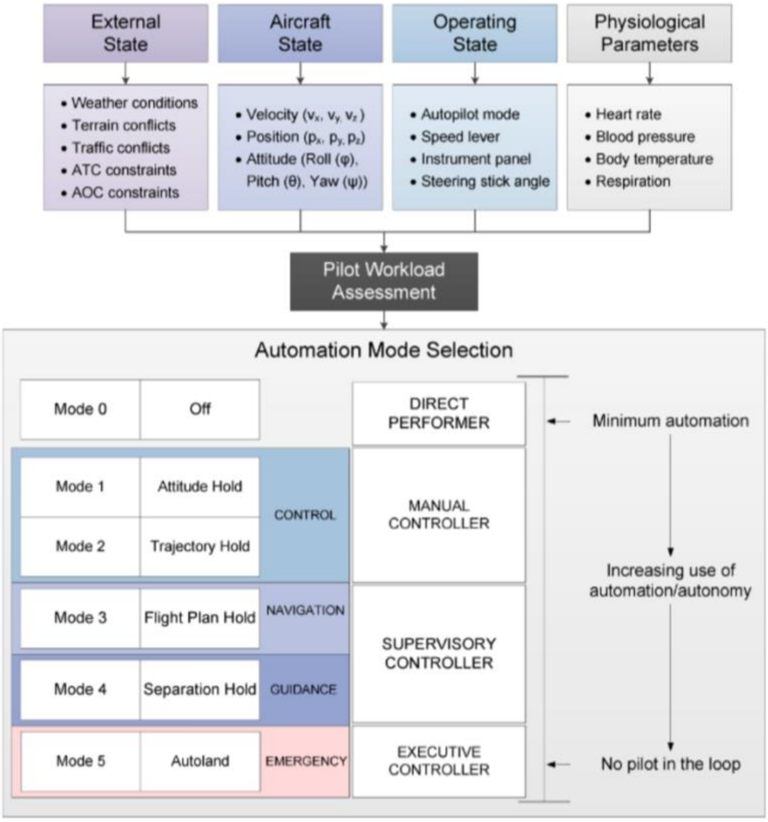

Figure 4 - VPA Functional Allocation Scheme (Gearhart, 2018)

GLOSSARY

- AAE: Académie de l’Air et de l’Espace
- ACFP: Autonomous Constrained Flight Planner
- AI: Artificial Intelligence
- CDU: Control Display Unit
- CPL: Commercial Pilot Licence
- EASA: European Aviation Safety Agency
- EVS: Enhanced Vision System
- FAA: Federal Aviation Administration
- FMS: Flight Management System
- FO: First Officer
- GPWS: Ground Proximity Warning System
- HAT: Human-Autonomy Teaming
- HMI: Human-Machine Interface
- HMT: Human-Machine Teaming
- HUD: Head Up Display
- ICAO: International Civil Aviation Organisation
- NASA: National Aeronautics and Space Administration
- PPL: Private Pilot Licence
- RPAS: Remotely Piloted Aircraft System
- SPO: Single-Pilot Operations
- TCAS: Traffic Collision and Avoidance System
- TCO: Two-Crew Operations
- TTC: Time To Completion
- VA: Virtual Assistant
- VPA: Virtual Pilot Assistant

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