The Future Impact of AI on the Human Role in Aviation: a case study of Pilots

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Abstract. Introducing Artificial Intelligence (AI) into commercial air transport operation is expected to remarkably impact future roles by 2050. This paper introduces the results of the EU Horizon Project HAIKU, where a series of workshops and interviews were conducted with subject matter experts (SMEs) in aviation to explore the key milestones in the evolution of human roles in industry. Furthermore, the paper presents the likely changes required by personality traits, skills and training through the example of commercial airline pilots, as one of the key roles impacted the most by the introduction of artificial intelligence in operation.

Keywords: Artificial intelligence, Human role, Human-AI teaming, Five factor model, Crew resource management, Knowledge management

1 Introduction: The impact of AI on the human role in future aviation

As a result of technological advancements, the role of humans in complex socio-technical systems is foreseen to evolve. As a result, the skills and knowledge that are required by the future workforce to accomplish everyday tasks will also change, mostly due to an increase in automation, and Artificial Intelligence (AI). Consequently, anticipating these future skills and knowledge is necessary to strategically design adequate training and educational paths and to ensure the smooth transition of professionals in the field [1], thus maintaining safe and secure operation within aviation. By 2050, AI might gradually become a full-fledged team member in the cockpit, ops rooms and airports. This opens to a set of questions that need to be answered to have a clear view of the future workforce and to ensure the continuity of a seamless and safe operation.

This paper reports the findings of the EU Horizon project HAIKU, where a strand of work was dedicated to the analysis of AI impact on the human role, and definition of recommended training approaches to address this challenge. More specifically, the analysis has focused on three aspects to investigate in relation to the introduction of AI into operations:

- What will be the impact of AI on the current human role in aviation?

- How will the required personality traits, skills and training change as a response to AI introduced in operation?
- How can the aviation sector maintain its attractiveness to future generations' workforce?

The recent paper introduces a set of empirical data collection procedures that resulted in the identification of 1) how the human role will likely evolve in aviation as a result of artificial intelligence introduction in operation; 2) how personality traits of commercial airline pilots, as well as hard and soft skills, and the way these skills are trained may shift in the future as a result of introducing AI in operation.

2 Step 1: Investigation of the evolution of human role in future aviation

In order to build a comprehensive understanding of the likely evolution of human roles in future aviation, three workshops with Subject Matter Experts (SME) have been organized to discuss and analyze the AI systems' introduction into operations, and identify the likely necessary changes in human roles, skill set and competencies.

2.1 Workshops on the evolution of the human role in future aviation

The three workshops took place in Italy, Sweden and Belgium, and involved *n=30* subject matter experts from 7 countries, covering all aviation segments, namely 8 SMEs from the ATM segment, 6 SMEs on UTM and UAM; 12 SMEs from airlines; 4 SMEs from airports.

The workshops were based on future scenarios (2050) developed earlier within the HAIKU project [2]. A variety of brainstorming methodologies were used to outline the human role's evolution from the present day to 2050. More specifically, relying on backcasting, forecasting and the lotus blossom methodologies, participants were able to explore and discuss the evolution of human role in a creative, yet systematic way, ensuring that no important aspects have been overlooked. Backcasting is a strategic planning methodology that involves working backward from a desired future scenario to the present, identifying the necessary steps and actions required to reach that future state. It is not focused on predicting the future, but rather on designing a pathway to achieve a specific vision by determining the policies, measures, and interventions needed to realize the desired outcome [3; 4]. Forecasting, on the other hand, is a method of projecting future values by analyzing current trends. It begins with the present as a starting point and extrapolates future trajectories to attain a desired future outcome [5]. In the context of the "Future Workforce Workshop" sessions, forecasting worked in tandem with backcasting, offering a comprehensive insight into both the existing state and potential future advancements. Finally, the lotus blossom method is a brainstorming technique that involves the systematic exploration of ideas around a central idea which can then be broken down into deeper sub-themes [6]. As a complementary research step, interview sessions have been organized with n=5 subject matter experts to further elaborate on the expected changes of key roles in aviation. In this paper, only the results of the role of commercial airline pilots are presented.

3 Step 2: Exploring pilots' future personality, skills and required training

In Step 2, the role of commercial airline pilots has been chosen as a specific role in aviation to demonstrate the likely change in the future job profile, the variety of tasks to perform along with the technical and soft skills required to perform these tasks successfully, and finally, the way these skills may be trained.

First, desk research has been performed to investigate the state of the art in the current personality profile required by commercial airline pilots, focusing on studies that applied the Five Factor Model or Big 5 (FFM) as a theoretical approach to personality [7]. As an important future challenge closely related to climate change, the frequency and severity of extreme weather events is expected to increase, demanding a stronger focus on situations in which they have a significant impact on the airline operation (e.g. the necessity to quickly re-route due to extreme weather event) or on the state of the pilot (e.g. a startling effect caused by a lightning strike).

Second, two workshops have been organized to understand the necessary skills of pilots in two potentially hazardous situations, where quick reaction to the changing environmental conditions is a key factor in maintaining operational safety, namely: (i) startling/surprising events in the cockpit, (ii) route re-planning. The importance of these skills was also discussed in a possible future, where "single pilot operations" may take place and an AI-based intelligent assistant is foreseen to support the pilot in the aforementioned situations.

Third, based on the comparison between the as-is and future operation, a gap analysis has been performed, highlighting the most relevant changes in the skill set and future personality of pilots that future training programs and selection procedures may take into consideration.

As the last step, a semi-structured interview has been conducted to reason on the necessary changes in future training. By completing these interlinking research steps, a variety of recommendations have been formed on the changing role of pilots in terms of personality in future selection (who to train?), the changing nature of skills to train in the future (what to train?) as well as the ways these skills could be trained in the future (how to train?).

3.1 Desk research: the evolution of personality traits of pilots

Personality is defined as a unique set of predispositions for a person to respond in particular ways. Personality permits a prediction of what a person will most likely do in each situation. These trait characteristics, being relatively stable over time, lead people to behave in distinctive and consistent ways across situations. As personality plays a key role in how individuals react to different situations, the personality of an aviator is very likely to have its own impact on how a pilot approaches different scenarios, including more demanding ones [8; 9]. While psychomotor skills and cognitive abilities have long been commonly employed in pilot selection, personality assessment as a means of predicting one's aptitude has gained incremental validity more recently [10]. Although there is an ongoing controversy of whether there is a unique combination of characteristics that make up the "ideal pilot", certain personality traits such as being emotionally stable, conscientious, agreeable, and extroverted have been identified as crucial for training success and later job performance.

One of the most commonly used personality indexes in assessing pilots' personality is the Five-Factor-Model (FFM), consisting in five major personality dimensions, often referred to as the "Big Five" of personality [7].

It includes the following factors: Openness to experience (O); Conscientiousness (C); Extraversion (E); Agreeableness (A); Neuroticism (N) [8; 11]:

- *Openness to experience* is defined as the degree of receptivity to a range of internal/external sources of information and new inputs.
- *Conscientiousness* is defined as the amount of persistence, organization, and motivation in goal-directed behaviors.
- Extroversion refers to the amount of energy someone directs outwards to the external environment.
- *Agreeableness* is considered as the quality of one's interpersonal interactions along a continuum from compassion to hostility.
- *Neuroticism* is defined as the one's propensity to experience negative emotions, such as anxiety or depression.

3.2 Workshops on future skills of pilots

To understand the transformation of current skills in the future, two workshops were conducted aiming at exploring the interactions pilots need to engage in for specific scenarios (startle/surprise; route planning/re-planning), both today (2023) and in 2035. Interaction here was defined as a reciprocal action between on the one hand, the pilot and other hand, other human actors, rules, procedures and regulations, the technical system, and the physical requirement. Following this logic, the SHELL model [12; 13] was used to systematically define all possible interactions between pilots and their environment. In this case, the SHELL model provided a comprehensive approach to understanding pilots' interactions with their environment and based on these interactions, the basis for reasoning on the transformation of required skills. Following the logic of the model, the following areas were investigated as aspects with which pilots interact during task execution:

- *Liveware (L):* e.g. cabin crew, ground crew, management, and administration personnel.
- *Software (S):* laws, rules, regulations, instructions, policies, orders, SOPs, safety procedures.

- *Hardware (H):* physical elements of the system (e.g. controls, surfaces, displays of the aircraft; operator equipment, tools, materials, buildings, vehicles, computers, etc.).
- *Environment (E):* the context in which humans operate the system (e.g. cabin/cockpit temperature, air pressure, humidity, noise, vibration and ambient light levels, weather conditions, visibility, turbulence, etc.). This aspect was defined by the participants of the workshop.

To investigate the changes in interactions, and consequently, the transformation of skills, two workshops for the two potentially critical scenarios (startle effect and route re-planning) have been organized, with *n=4* participants involved in each session. Participants were, on the one hand, developers of the AI-based intelligent assistants to support single pilots in the future in cases of startling effect and re-route planning. On the other hand, among the participants there were professional pilots of European commercial airlines. The duration of the workshops was 2,5 hours. To ensure that all the important inputs were registered, each session was managed by two facilitators, and key conversations were audio recorded.

The workshop sessions were built around the following two use cases (UC) of how the AI-based intelligent assistants aim at supporting pilots in the aforementioned situations:

- UC#1: The FOCUS ("Flight Operations Companion for Unexpected Situations") AI-based assistant aims to support pilots during startling and surprising events in the cockpit. These events sometimes provoke "freeze" reactions, delay in response time or inappropriate cockpit inputs and can lead to accidents. Startle refers to a stress response to a sudden intense stimulus, whereas surprise is a cognitive and emotional reaction that results from the mismatch between pilot's expectations and reality. As they have an interactive negative effect on performance, they may seriously impair a pilot's ability of troubleshooting and immediate procedural actions [14]. To tackle this, FOCUS aims at offering real-time assistance to commercial pilots, detecting startle events, helping them regain emotional stability and situation awareness. To facilitate the pilot's recovery from initial surprise, the intelligent assistant initiates a collaborative procedure, guiding them in regaining situational awareness and making the necessary decisions for a safe landing.
- UC#2: The intelligent assistant in this case aims at supporting pilots in route planning/replanning ("Flight deck route planning/replanning"). Replanned routes result from new constraints and different hazards, such as weather changes that prevent pilots from landing at their originally targeted airport. Re-planning a route, although based on previously defined alternative routes, requires pilots to adapt to changing circumstances and make decisions in a timely and effective manner. The intelligent assistant developed in UC#2 is supports pilots during the flight by translating pilots' high-level intentions into technical flight parameters. As an example, the case of a flight from Bordeaux to Munich was presented, which was delayed by 2 hours. Upon arrival above Lyon, the snowstorm that was forecast turns out to be more severe than anticipated and all the airports in Northeast Europe begin to close. A new route is needed. Options include continuing to Munich, landing in Zurich but unable to reach Munich, or landing in Lyon with a subsequent flight to Munich. Returning to Bordeaux is also feasible. The intelligent

assistant compares options, consults services, and prioritizes based on the pilot's intentions (e.g. which criterion to prioritize among airline profitability, pilot workload, passengers' comfort), ensuring effective decision-making.

Participants were first asked to identify today's elements of interactions, then they were asked to perform the same procedure in the same scenario, but referring to 2035, once the intelligent assistant is in operation. Based on the two SHELL boards, a gap analysis was performed, identifying areas of major changes in interactions in the future. Having these major changes in mind, a set of new skills that would be required by pilots to successfully engage in those future interactions was defined.

3.3 Semi-structured interview on future training

As the last step, a semi-structured interview with one flight instructor from a commercial airline was conducted to elaborate on the key aspects of the workshop results, as well as to reflect on the required modifications in training content and format, in order to align with the envisaged future changes. The interview session was built around the following main questions:

- *Having a vision of how the tasks related to this role will change by 2035, how do you envision key skills and competencies to change accordingly?*
- *What kind of new skills are likely to emerge?*
- *What kind of skills are likely to become less relevant?*
- *How will the existing skills be modified in terms of meaning/content (e.g. communication skills - with human/with AI)?*
- *How do you think current training should be changed to cover this modified set of skills and competencies?*

Finally, combining the results of the interview with the outcomes of the previous steps, recommendations on the targets, the content and the format of future training were formulated.

4 Results

4.1 Commercial Air Transport Human-AI Teaming Roadmap: from today to 2050

By 2050, AI might gradually become a full-fledged team member in the cockpit, ops rooms and airports. Based on the results of the workshop series conducted with subject matter experts in Step 1, the following overarching trends are envisaged as most probable from today to 2050, forming a high-level roadmap for future human roles in aviation as a response to the introduction of AI into operations.

The steps outlined below are coherent with EASA and SESAR AI Roadmaps [15; 16]. All the participants were familiar with these roadmaps; therefore the main key aspects were considered into the HAIKU roadmap. The major difference lies in the focus, with HAIKU roadmap concentrating uniquely on the human perspective on technological changes, on the impact on human skills and competencies.

Between 2025 and 2030

This timeframe is characterized by increased and heterogeneous air traffic managed in segregated airspaces [2]. AI is expected to start supporting Commercial Air Transport operations by assisting humans in identifying optimal solutions and priorities (e.g. in case of medical emergencies on board the aircraft). Especially in the cockpit, a few initial simple and repetitive tasks (e.g. frequency management and taxiing) may be delegated to AI systems. The human role is not expected to change much from now until 2030. In fact, human operators are expected to still be in charge of the majority of tasks, problem solving and decision making. However, these 5 years are expected to be key to:

- Start building a strong relationship of trust between humans and AI, a critical success factor to allow the aviation industry to be open and welcome AI into commercial air operations.
- Re-design roles and job profiles for the forthcoming years according to the technological evolution in the sector, to ensure having the right people, well-trained and equipped, ready to safely and securely operate in the following years.

In the SESAR Roadmap, this corresponds to automation Level 1, and the same applies for EASA's Roadmap.

Between 2030 and 2035

The timeframe is envisaged to be a critical transitional phase characterized by higher operational complexity (still managed by segregation), increased role of AI systems, and consequent regulatory changes. Humans are expected to be key to successfully leading and achieving this transition phase. Some existing roles may be revised, and new temporary ones could be introduced, with a view to shifting human values and contributions from operational positions to more managerial ones.

During these 5 years, AI is expected to assist humans in workload management and be in charge of performing the majority of repetitive tasks (e.g. voice communication) as well as some initial complex tasks for which a transition by segregation is foreseen (e.g. starting from off-peak and night-time slots). Humans are envisaged to remain responsible for the majority of complex tasks, problem solving and decision making, while starting to team up with AI.

The quality of the human-AI interactions may be a crucial success factor in this time frame. Indeed, this would be one of the key elements enabling the creation of an effective learning loop between humans and AI. Furthermore, when delegating tasks to AI, preventing degradation skills will be a must to maintain high safety standards.

The following 5 years are likely to be characterised by the consolidation of important changes from three areas:

- Technological, with the accomplishment of the digitisation process which opens the door to more and more AI applications;
- Operational, with the activation of the shift from segregated to integrated airspace;
- Human, with important changes in roles and responsibilities, and the introduction of new ones.

In the SESAR Roadmap, this corresponds to automation Levels 2 and 3, while in the EASA Roadmap it is Level 2.

Between 2035 and 2040

Within this timeframe, nominal situations are expected to be managed by technological and AI-based systems which will also alert humans to potential risky situations and hazards. AI would also be in charge of coordinating the integration of airspaces as well as harmonizing and standardizing systems across international actors. Human operators are expected to monitor and intervene in case of non-nominal situations.

Ensuring and sustaining human situational awareness, vigilance and system knowledge is expected to be the key challenge for this time frame.

The envisioned concept reaches Level 4 in SESAR Roadmap, and Level 3 for EASA the EASA Roadmap.

Between 2040 and 2050

A progressive strengthening of the relationship between humans and AI is expected to characterize the 2040-2050 decade. AI may extend its contribution to non-nominal situations, providing advice and directly intervening in case of imminent risks. Humans are expected to mostly intervene, teaming up with AI, in case of non-nominal situations. Societal trust and acceptance may be the major challenge during the 40s.

Looking at the whole picture, ensuring desirability of the human role and retaining aviation job attractiveness and people's motivation are expected to be the major challenges for the industry. People may be willing and happy to welcome AI in operations and teaming up with it, but only if important benefits are perceived not only from the economical and operational perspectives, but also from the safety and human ones.

Similarly to the previous time frame, this concept reaches Level 4 in SESAR Roadmap, and Level 3 for EASA the EASA Roadmap.

4.2 The evolution of Pilots' role towards 2050

The 2050 reference scenario for Flight Operations foresees Single Pilot Operations (SPO) for both long-haul commercial and cargo flights, considering single pilots in the cockpit supported by on-board, AI-based and intelligent assistants and automation, which would take care of the majority of the Pilot Flying and Pilot Monitoring tasks in nominal operations [17]. In view of this technological and operational trend, during the 2040s the Pilot Flying is projected to progressively absorb some of the Pilot Monitoring tasks.

The Pilot Flying, when in a Single Pilot setting, is expected to assume a more supervisory role during nominal operations, while his/her contribution and competencies would be key in case of non-nominal and emergency situations. In these cases, s/he is expected to be supported by on-board AI systems as well as by remote human assistants. This new role, named Flight Ops Ground Monitor, can be considered as an example of the evolution of Pilot Monitoring. It is projected to support SPO from the ground, monitoring multiple flights at the same time and providing support when Single Pilots need assistance. In case of Single Pilot incapacitation, on-board autonomous landing systems would intervene.

4.3 Who to train: a comparison of pilots' personality traits today and in the future

Pilots' personality traits today

When it comes to assessing personality traits in aviation, the majority of studies show that pilots, compared to the general population, score lower on Neuroticism, indicating a profile with more balance and emotional stability. This could be due to the need to be less reactive to stress in an industry which is by nature a high stake/high stress environment. With respect to Extraversion, empirical data suggests that the pilot population has higher levels of Extraversion compared to the general population. Sociability is typically an important characteristic in commercial aviation, where pilots perform their tasks in a team context. Apart from communicating over the radio, they need to socialize with their fellow pilots and cabin crew (for passenger aircraft) with whom they can be confined for several hours during operations. Openness to experience is a personality trait that does not seem to differentiate between pilots and general population, as both tend to score equivalent on this scale. A possible explanation lies in the nature of the aviation industry: as the job of pilots is highly procedural, there may be less need for a pilot to be creative, adaptive, and receptive to changes. With respect to Agreeableness, pilots in general tend to be less agreeable than the general population, however, in the case of commercial pilots, results are mixed (compared to military pilots and pilots-in-training). This again might result from their higher need to effectively work in a team context where the ability to build trust quickly in a constantly changing crew is crucial. In the case of Conscientiousness, the pilot population appears to trend somewhat higher than the general population, however, this tends to be less of a pattern in the case of pilots-in-training, presumably due to their age, compared to professional pilots in commercial aviation or in the military [11]. While in comparison with professional pilots, pilots-in-training seemed to score somewhat lower on Conscientiousness, a meta-analysis found this personality trait to be a significant positive predictor of training success, along with low levels of Neuroticism. In other words, student pilots, reporting high levels of Conscientiousness and low levels of Neuroticism appeared to have slightly better chances of passing their flight training successfully [10].
In summary, today's operational context in aviation may require pilots to be emotionally stable, extroverted, agreeable, and conscientious with less importance given to being open to experience.

Pilots' personality traits in the future

Long-term changes in the aviation industry are envisaged to bring significant changes in pilots' job context in terms of who they will team up with in the cockpit. Pilots are foreseen to be gradually accompanied by AI, and this is a change that may redefine the typical personality traits of future pilots. The following results on future personality

traits are based on the workshops conducted in Step2, and where needed, they are supported by literature:
One important aspect of this anticipated change is related to the social isolation of future pilots [17]. Pilots are expected to have significantly fewer human interactions, exposing them to potential boredom and loneliness in the cockpit. The reduced number of social interactions may favor those who need less external and social stimulus, feel comfortable working alone and may be more indifferent to their direct social environment. In addition, being isolated in the cockpit may require future pilots to be even more stable emotionally, as direct social support in stress management will be reduced and pilots may need to have an even better ability to self-regulate their own emotions and anxiety.
Another important aspect of future change will be pilots' willingness and efficiency to team up with AI. General attitudes towards the use of AI may have a significant impact on the skilling, up-skilling and reskilling of professionals in the aviation industry. Therefore, it may be worthwhile to further investigate whether certain personality traits have the potential to predict these attitudes. As individuals who score high on Openness to experience tend to be more innovative and open to new experiences, pilots with higher scores on this scale may exhibit more positive attitudes and acceptance towards teaming up with AI and switching to new technologies, along with a willingness to enroll in new training that these changes require [18]. Similarly, it might be reasonable to think that a higher level of Agreeableness could be linked to more positive attitudes towards the acceptance of AI. As empirical data shows, individuals who score higher on Agreeableness tend to be less skeptical and more tolerant towards the negative aspects of AI [19].
All in all, envisaged changes in future operational context may require future pilots to possess a slightly different personality profile compared to the traits they tend to have today. In the future, an even higher emotional stability and lower level of Extraversion may be required by pilots to be able to cope with reduced human interactions and social isolation, while a higher level of Openness to experience and Agreeableness may be needed to develop positive attitudes towards the use of AI that might affect success in skilling, up-skilling and reskilling.
Personality assessment will most probably continue to play a vital role when it comes to selecting pilots. Considering the high cost of dropouts and substandard performance, a valid and meticulously designed testing of personality traits that takes major future changes into consideration may be vital.

A revision of recruitment strategy

An inevitable supplemental process to reconsider is the recruitment of future pilots to be trained. The anticipated changes in future aviation will certainly require revision on to whom, through which channels and how the future role of pilots should be promoted in order to ensure a sufficient pool of applicants in terms of both quantity and quality. As the envisaged future work environment might be even more difficult to fully imagine for applicants with no real experience in the cockpit, recruitment processes should consider techniques that offer a comprehensive introduction to this future role, with detailed explanations on the tasks, as well as the pros and cons related to the role. One recruitment technique to recommend based on its potential to provide a 360-degree picture on jobs could be a Realistic Job Preview (RJP). This recruitment technique is often associated with the implicit process of self-selection, as it offers a realistic view on the job, thus reducing the probability of mismatch between applicants' competences & needs and the characteristics of the job. Formats may include brochures, testimonial videos of pilots, interactive digital work stimulations, videos, etc. While there is a reasonable motivation to attract top-level candidates for training, offering a realistic (not sugar-coated), tangible picture of what a role will look like would support candidates in developing realistic expectations towards their job and career path [20]. To mitigate potential shortcomings on the number of future applicants, the aviation industry should prepare a proactive strategy to anticipate and understand the needs of future generations related to their job and career path as well as to build an action plan on how these needs can be fulfilled in the envisaged, AI-based work environment. The successful and realistic identification of what the future role of pilots requires and what it has to offer would contribute to a better match of candidates' profile and job requirements, thus keeping potential dropouts at the lowest possible level.

4.4 What to train: transformation of pilots' skills in the future

Use Case #1: Flight deck startle response – changes in interactions based on the SHELL model

Liveware: in the future of reference, a "single pilot operation" (SPO) configuration is envisaged, resulting in the pilot flying being in control of the aircraft. Although less resources would be spent on human coordination and communication, pilots would also lose the monitoring ensured by their co-pilot. Co-pilot's cross checking is an important means to ensure that situational awareness is correctly built, system data and parameters are correctly interpreted, and crew members are on the same page during flights. The anticipated lack of spontaneous communication and the non-verbal communication channel is an important related challenge (although non-verbal communication will partly be replaced by biophysical data registered by the IA). Spontaneous, oral communication is an important means of reducing stress and providing social and emotional support under stress, as well as overcoming a potential startle effect. In addition, social isolation itself is a topic to be addressed when identifying future challenges related to SPO configuration. Pilots reportedly need to be able to talk to someone during flights, for which a Generative Pre-Trained Transformer (GPT) chatbot might be able to provide an alternative solution in the future. Furthermore, oral communication is found to be an important need of pilots in re-building their situational awareness, after a startle effect has taken place. Trust issues related to accepting the support of an AI-based assistant is another challenge to consider. Trust must be neither too high, to avoid overreliance, nor too low, to avoid an increased workload due to multiple evaluations of the AI outcomes. Related to that, pilots in the future might need to learn additional stress management skills (e.g. biofeedback techniques, breathing and relaxation techniques, mindfulness, etc.) in order to successfully self-regulate their own emotions during flights. Detailed technical knowledge on how the AI-based IA supports pilots during flight might also be important in order to address the issues related to trusting the new system. Finally, communication and coordination skills will most probably need to be modified or extended to include ways of effective collaboration with an AI-based teammate. More specifically, a new framework and systematic procedure is needed to support pilots in deciding when and how to call their AI-based teammate into action, what type of information or message to convey to their AI-based teammate and to their human co-actors (cabin crew, ground operation, etc.) and how to build a shared understanding of the crew as a whole.

Software: As human teammates are envisaged to be absent from the cockpit in the future, pilots' decision making, adherence to procedures and the correct execution of these procedures will not be discussed and cross-checked by a team of humans who share the same physical location. Future single pilots under high stress may develop a so-called tunnel-vision, focusing on a limited number of parameters in the cockpit and/or by looking for parameters which reinforce their line of thinking. Therefore, they may need to develop enhanced skills in self-critical thinking and the ability to question themselves before making decision. The envisaged human-AI teaming in the future will also require the modification of the CRM procedures, to describe ways of collaboration with the AI teammate.

Hardware: During surprise and startle events, IA is expected to activate itself by certain biophysical parameters (e.g. gaze behaviour, heart rate, etc.) which indicate that the pilot is under startle. Though this can be controlled manually, the interaction between the two teammates is envisaged to be initiated by the IA, leaving the pilot in a more passive and less spontaneous role within the communication loop. To recover from startle, pilots will be expected to master self-relaxation techniques. To regain situational awareness, pilots will need to look at certain key parameters on the cockpit display, guided by signals. If the pilot is looking at these key parameters long enough, the IA will turn itself off, assuming that the pilot has regained situational awareness. Guiding signals on the display might be an efficient way to focus a pilot's attention in case of startle but may also potentially lead to information overload in a cognitive state in which pilots are already struggling to interpret cues from the environment. Furthermore, the application of auditory inputs (voice instructions) besides visual cues might decrease the chance of information overload, by dividing information across modalities. In addition, staring at the displays for an extended period of time does not guarantee enhanced situational awareness if these pieces of information are not actively elaborated ("look but not see" effect). Future knowledge of procedures and checklists to actively assess one's level of situational awareness may be an important additional support in regaining situation awareness during stressful events.

Use Case #2: Flight deck route replanning – changes in interactions based on the SHELL model

Liveware: in the future of reference, a "single pilot in cruise" (SPIC) configuration is envisaged: one pilot in command during the cruising phase while the second can rest and then take over, but both pilots are present for the preparation, taxiing, take-off, descent and landing phases [21]. Pilots flying will have an advanced support system in making their decision about alternative airports. The intelligent assistant is anticipated to integrate key technical parameters, preferences of different actors and suggest solutions accordingly. While pilots today are trained to integrate parameters from multiple

sources and decide based on them, decisions on alternative routes in the future are expected to be based on one single source of information: the intelligent assistant. Therefore, more critical thinking, the ability to question the system and advanced theoretical knowledge about human decision making may be needed in the future. Relying on AI in decision making will also require the ability to understand and trust the system. In addition, pilots in this future context will be required to self-assess their own cognitive comfort, including how comfortable they are with the suggestion of the intelligent assistant. The introduction of AI is also anticipated to impact on the team dynamics of the two pilots. As the intelligent assistant is expected to assist the pilot flying in the decision making, a challenging question will be when to call the other pilot into action, and how to brief them. The introduction of AI may result in a difference in how pilots resting rely on information coming from the pilot flying versus the information coming from the intelligent assistant.
Software & Hardware: In the anticipated future of reference, the intelligent assistant is expected to assist in prioritizing intentions and taking over the procedure of performance calculation. Pilots, as a result, will be required to learn new procedures involving intelligent assistant. As decision making is supposed to be based on one source of information, trust or overreliance in the system will be an important factor to consider. Even if suggestions are proposed by the intelligent assistant, pilots need to remain part of the process. This way, they will be able to actively and critically evaluate these alternatives as well as to maintain situational awareness, anticipate future steps ("being one step ahead of their aircraft") and take over control from the intelligent assistant on the procedure of performance calculation, whenever necessary.

A new training perspective: the AI-CRM

Traditional Crew Resource Management (CRM) has revolutionised cockpit safety by emphasising communication, teamwork, and decision-making skills. Integrating AI assistants as full-fledged "teammates" within an AI-CRM framework might present a promising next step in this evolution. Future changes in the crew composition, more specifically the envisaged future human-AI teams [2], will require an update of existing CRM, which should also be captured in the pilots' competency model. Indeed, the model should evolve according, considering the impact on the teamwork area and perhaps accommodating this new type of collaboration as a new competency.
Combining these assumptions with the findings presented above, we argue that the most appropriate training pathway to follow towards 2035 could be a CRM update, considering AI as an effective operative member of the aircrew. By treating AI assistants as teammates, not merely as decision aids, this framework fosters a deeper collaboration, which is continuously leveraging on AI's strengths in data analysis and risk assessment while ensuring that human judgement and skills remain central.
Therefore, considering the CRM Training Table of the EASA Regulation 1178/2011, we defined the following areas as the backbones of a potential future AI-based crew resource management:

- *Stress & Workload Management:* while AI could take on tedious tasks, thus reducing overall workload, managing trust dynamics and potential over-reliance on automation would become crucial. CRM training would need to address concerns about automation bias and equip pilots to effectively delegate and monitor AI performance, potentially mitigating new sources of stress. Integrating AI adds another layer of complexity to the cockpit environment. Pilots might experience stress by managing the AI system, understanding its outputs, and ensuring its proper functioning, while feeling underwhelmed when facing critical situations. In particular, for SPOs, future trainings should provide advanced skills of emotion regulation techniques, a deeper and more detailed understanding of both psychological and physiological aspects of stress, such as the impact on situational awareness (i.e., startle effect; tunnel-vision, losing chance to anticipate future steps), and how to act on them both with short- and long-term strategies, and with an advanced skill-set to assess one's cognitive, physiological and emotional state during flight.

- *Situational Awareness:* if pilots become overly reliant on AI for information processing and decision support, they might lose critical situational awareness skills developed through traditional CRM training failing in perceiving all the necessary aspects of the surrounding environment (breakdown in step 1 – perception), without exploring them actively, failing in understanding them (step 2 – comprehension), or failing in projecting them into the future (step 3) [22], bringing to agreeing with incorrect recommendations [23], changing their mind to match AI recommendations [24], or weighting too much the AI recommendation [25]. The CRM of the future should therefore cope with this challenge by training pilots on how to collaborate with AI on data processing to significantly enhance situational awareness by providing comprehensive analysis and real-time updates. Regarding situational awareness, CRM of the future should address the skill of gaining and re-gaining control and information quickly in nominal operations, after sleeping and in startle events. From a technical perspective, the interaction with explainable AI-based IAs will be a key factor in enabling pilots to recover from a mismatch between what is expected and what is experienced (Situational Awareness first level - Perception) and to anticipate future steps (Situational Awareness third level - Projection to future) [22].
- *Communication & Teamwork*: clear and concise communication would remain fundamental, but the focus might shift towards effectively conveying human intent and goals to the AI teammate, and vice versa. Sperber & Wilson [26], following the studies of Grice [27], define communication as the expression and recognition of intentions. While AI can process and generate information efficiently, its lack of human-like expressiveness can hinder communication flow. Therefore, differences in communication styles and information processing between humans and AI could lead to misunderstandings. Pilots and crew might misinterpret AI outputs or struggle to convey their intent and goals effectively, potentially hindering teamwork and decision-making. CRM training would need to address potential communication barriers and communication hazards due to differing processing styles and ensure that all team members (human and AI) have a shared mental model. Therefore, communication with AI could be addressed by deepening the concepts of on-demand communication (i.e., non-spontaneous), without

clues usually used by humans to increase consistency in communications (i.e., absence of non-verbal modalities).

- *Leadership & Control over automation*: excessive trust in AI recommendations could lead to complacency and reduce the pilot's ability to make independent decisions, thus potentially creating dangerous situations when manual intervention is needed. Moreover, managing a crew with humans (e.g. cabin crew, ground operation) and AI-based actors, adjusting communication practices, content and style to the needs of the different actors may be challenging. The CRM should therefore address these challenges, aiming to develop a leadership model that encompasses the management of human-AI teams, fosters trust, and ensures clear communication and delegation of tasks and considers both a human communication model and a data-driven approach. To foster effective control over automation, deep knowledge of both generic motoric skills to prevent skill loss (e.g. eye-hand coordination), transversally applicable and technical skills to understand AI behavior will be required. Training these skills will increase the human ability to take control whenever needed.
- *Problem Solving & Decision Making*: implementing AI as a teammate in an air crew may be helpful to pilots in various aspects: first, it provides support in analyzing vast amounts of data and presents pilots with insights and recommendations on how to enhance human capabilities. It also allows pilots to free up cognitive resources by taking over tedious tasks. Finally, it could play a key role in overcoming human biases such as overconfidence and anchoring, by presenting different perspectives. At the same time, blind reliance on AI recommendations can lead to automation bias, where pilots neglect crucial information, and if AI decision-making lacks transparency or explanation. This overreliance may result in a "black box" effect, hindering trust and making it difficult for pilots to critically evaluate recommendations and potentially leading to flawed decisions. Finally, complex ethical issues may arise in flight decision making. Pilots need frameworks and support to navigate these situations with responsible and transparent decision-making, even when they are influenced by AI. A specific recurrent training aiming to enhance basic digital literacy of pilots could also support the development of a decision-making process which considers the different AI communication and processing style, limiting biases such as data misinterpretation or failures in coordination between humans and AI. To foster an effective future decision-making, other skills such as critical thinking will need to be enhanced to mitigate false positive and false negative solutions provided by the AI-based assistant, having the right situational awareness to correctly question the received support.

4.5 How to train: recommendations for future training and knowledge sharing

In addition to the anticipated changes in what skills and knowledge will be crucial to address during training, another important question will be how to teach them in the future. The format of training may have a key impact on whether and how effectively these new skills are acquired and applied in real-life situations. Continuous technological developments in the aviation sector require an increasing number of new technical skills, resulting in an education path for pilots that is mostly based on formal training. On the other hand, the subjective experiences, know-how, perceptions, and attitudes of professional pilots represent an important and valuable form of knowledge. As required technical skills and procedures might slightly differ among airlines, the related know-how and experiences of pilots also represent a collection of tacit knowledge being unique to each airline. If collected and shared effectively, this knowledge could be an important additional asset in training future pilots as well as overcoming the initial difficulties of teaming up with AI.

Nonaka and Takeuchi's "SECI" model [28] of knowledge management represents a practical approach to how knowledge within a company is created and re-created, as different forms of explicit and tacit knowledge are continuously transforming into one another. According to the model, the four forms of knowledge creation are:

- *Socialization* (tacit to tacit): a form of knowledge sharing that is based on physical proximity. During socialization, knowledge is shared and captured by direct observation, imitation and/or practice through apprenticeship.
- *Externalization* (tacit to explicit): the other form of knowledge sharing, during which tacit knowledge becomes explicit, crystallized, and shared with others, thus becoming the basis of new knowledge. This way, personal tacit knowledge becomes useful for others in an explicit, understandable, and interpretable form (e.g. concepts, documents, images).
- *Combination* (explicit to explicit): it involves the organization and integration of knowledge, whereby different forms of explicit knowledge are merged, and finally a new form of explicit knowledge is created. Examples of combinations involve writing a report or building a prototype.
- *Internalization* (explicit to tacit): the receiving and application of explicit knowledge by an individual. Explicit knowledge becomes part of an individual's knowledge base, typically by the act of learning-by-doing.

As was highlighted during the semi-structured interview, pilots-in-training today acquire knowledge mostly through the process of internalization and socialization. By acquiring theoretical knowledge on aviation and by practicing technical and non-technical skills on a simulator (learning-by-doing) they internalize explicit knowledge that is required to become a pilot. This internalized knowledge is then expanded and fine-grained by observing the other pilot during flights, in other words, a form of socialization takes place. Externalization as a knowledge sharing form, however, is often present in a less formal and therefore ad-hoc form, resulting in valuable subjective experiences and best practices remaining unshared.

On the other hand, unexpected events or other stressful, high workload situations often provoke intensive subjective feelings and emotions, like frustration, insecurity, lack of control or even fear. These subjective experiences may activate very diverse individual reactions, from which some prove to be successful, thus turning into a recurrent coping skill, in other words, the best practice of the individual. These subjective feelings and related coping mechanisms are, however, prone to remain unshared, even though they could be important knowledge accumulated and shared within the company. This is mostly due to the prevailing masculine organizational culture within aviation [29] where - as pinpointed during the semi-structured interview - talking openly about emotions and personal weaknesses is still a challenging area. A potential mitigation strategy could be the application of formally organized focus group sessions, facilitated by psychologists. These sessions would provide an opportunity to share individual best practices and make them explicit. Based on that, the collection, organization and sharing of this knowledge would ensure that it becomes part of the knowledge management spiral, and thus, part of the organization's collective knowledge. The presence of a facilitator, on the other hand, would give a guarantee that a psychologically safe atmosphere is provided for pilots to talk about their subjective experiences openly and freely.

Anticipated changes in the future related to AI will also result in a major transformation of airlines' existing knowledge base. A considerable amount of explicit and tacit knowledge will likely become outdated and irrelevant, as technology and the related procedures, regulations and policies will transform radically. On the other hand, new forms of explicit knowledge will be required, and along with that, a remarkable amount of new know-how will be accumulated in the form of tacit knowledge. This knowledge, if shared and organized efficiently, could be channeled into the future training of pilots, thus accelerating successful human-AI teaming. Organizations in the aviation sector are therefore highly encouraged to build a proactive strategy on how to consciously manage organizational knowledge in the future, when AI will become an important actor in the cockpit. One challenging aspect of this transformation would be to discover how an AI teammate could be involved in the organization's knowledge management spiral. A potential area in which AI could play a key role in the future is the process of Combination, during which AI-teammates would create new forms of explicit knowledge by merging different sources of already existing explicit knowledge. AI will most likely also be crucial in the storage, organization and provision of explicit knowledge when needed in the cockpit.

Changes in the future do not only call for new forms of training among pilots: flight instructors are also expected to be up-skilled to develop new knowledge and a detailed understanding of the systems on which they train their students, as well as the related technical and non-technical skills. In addition, flight instructors in the future will likely face the challenge of the different training requirements related to the skilling and re-skilling of pilots. In other words, a detailed understanding will be needed on what and how to train students with no previous knowledge in aviation and professional pilots who need to overwrite already existing knowledge. Moreover, some instructors may be expected to experience difficulties in training due to potential negative attitudes or initial resistance towards learning and re-learning a system where AI acts as full-fledged teammate in the cockpit. Therefore, it could be important that flight instructors receive regular feedback and supervision from several different professionals (flight instructors, psychologists, pedagogues) on the way they train in forms of "train the trainer" sessions. This guided feedback would support them in the future to maximize the effectiveness of training, as well as enable them to provide personalized forms of education to students, be they new cadets or re-skilled professional pilots.

5 Conclusions

Undoubtedly, new technologies and, more specifically, AI are powerful means to support aviation operators, allowing the industry to safely and effectively face the envisaged rise in traffic complexity, due to increased demand and heterogeneity in traffic. However, technological evolution is expected to significantly change the human role. AI may gradually absorb human tasks, probably leading to a significant change in the workforce landscape in the next 30 years. In fact, some roles are expected to change others to become obsolete and new roles may be introduced.

AI, as a promising future direction in aviation, is undoubtedly expected to require a novel approach in how humans operate successfully within this industry. In addition to being a supporting tool for pilots in finding optimal solutions or priorities, future IAs are also envisaged as full-fledged, active, and key actors in the cockpit. Therefore, to anticipate the requirements and prepare for a potential future where humans team up with AI is crucial.

This process should start with systematically revising recruitment strategies and the key principles based on which future pilots are selected for training. The radical change in the working environment may result in current recruitment trends becoming outdated. As new generations will gradually enter the aviation industry, understanding their career needs and matching them with what the envisaged future work environment has to offer will become a priority in human resource management.

Similarly, personal characteristics that are likely to predict a high job performance today may change consistently, as future pilots will most likely require a personality profile with more openness and trust to collaborate with new technologies and less need for social stimulation and human interactions. A potential revision of the personality profile of future pilots could save important resources for companies in terms of time and costs, as the successful selection of pilots may minimize the risk of dropouts and attrition in later career stages.

The required technical and non-technical skills to become a pilot will need to be modified and extended by the aspects of collaboration with an AI-based teammate. By developing a detailed understanding of future skills and by breaking them down into tangible behavioral indicators would not only support smooth human-machine interaction, but they would also serve as new anchors of selection and performance appraisal thus ensuring a valid process of aptitude testing.

Finally, the way this modified skill set will be trained seems to be another interesting area to revolutionize in the future. As the transformation of the work environment, the ways of working as well as the requirements on technical and non-technical skills will necessarily result in the accumulation of new explicit knowledge and implicit know-how, defining effective ways of knowledge management and training formats in which these new knowledge and know-how can be successfully acquired will be a key in maintaining human performance and aviation safety.

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Acknowledgments. This publication is based on work performed in the HAIKU Project (Human AI teaming Knowledge and Understanding for aviation safety) which has received funding from the European Union's Horizon Europe research and innovation program, under Grant Agreement n.101075332. Any dissemination reflects the authors' view only and the European Commission is not responsible for any use that may be made of information it contains.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.