Optimizing Decision Making in Aviation: A New Communication Paradigm for Rerouting

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Abstract: Commercial aviation is increasingly constrained by airspace congestion and the need to balance profitability with environmental concerns. Despite this growing complexity, pilot's cognitive resources remain the same. This article examines a new communication paradigm using 'intentions' in HAT (Human Autonomy Teaming) for commercial aviation. The use case involves a cockpit IA (Intelligent Assistant) designed to assist flight crew in re-routing or diverting an airliner to a new destination in the event of weather hazards, taking into account various operational performance indicators. To communicate and negotiate with the IA, the pilot expresses their high-level goal, also known as operator intention, which includes preserving cognitive capacities, passenger comfort, or airline profitability, in order to find the optimal solution. This work compares three types of assistance: decision support, cooperative assistance, and collaborative assistance. The study aims to identify the key features of each type and determine the most suitable level of assistance for supporting decision-making during rerouting. To validate the objectives of this use case, six pilots were asked to evaluate three different types of assistance using the 'cognitive walkthrough' method and questionnaires about trust and usability. The results provide some key features of each type of assistance that can increase the performance of decision making in a distributed work between pilot and IA.

1 INTRODUCTION

Safety has always been a paramount consideration in the civil aviation industry (Li et al., 2023). With the worldwide rapid growth of airlines' operations, the importance of aviation safety and risk is becoming more prominent. Over the past decades, the use of intelligent systems in aircraft has increased exponentially, promising to revolutionize the safety, efficiency, and comfort of air travel. Artificial intelligence technologies are expected to play an exceedingly crucial role in the future of the aviation sector. Investments in artificial intelligence, which amounted to approximately $340 million in 2019, are projected to reach $3.7 billion by 2027, with a compound annual growth rate of 45.3%. This trend is expected to further intensify the aircraft where they are anticipated to be equipped with sophisticated artificial intelligent (AI) systems, playing a crucial role in decision-making, and pilot's assistance (Ceken, 2024). Such sophisticated AI systems are likely to transform human-machine interactions to Human-Autonomy Teaming (HAT), in which team-oriented intentions, shared mental models, and some decision authority to determine actions, allow

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systems to effectively coordinate with humans in complex tasks (Lyons, et al., 2021).

This exponential growth stems primarily from the industry's constant pursuit of enhancing aviation safety. Various types of aviation accidents, such as loss of control in flight (LOC-I), unexplained or undetermined incidents (UNK), Controlled Flight Into Terrain (CFIT), as well as system or component failures, have prompted a thorough revaluation of existing safety protocols (Li et al., 2023). These incidents, often attributed to human error or unforeseen environmental factors, have highlighted the need for technological assistance for pilots to manage complex situations and systems, particularly in critical flight events.

1.1 Human Autonomy Teaming

Recent research into intelligent systems has centred on exploring the viability of HAT, which would serve the dual purpose of managing new assistance onboard and providing support to the pilot during periods of high workload. It's an innovative technique for user control and review of decision making (Saephan, 2023). The Challenge in HAT lie in creating (1) opportunities for teams to build shared awareness and collective motivation, (2) comprehension of the tasks and interactions that can gain from social cueing, and (3) devising methods to utilize these cues effectively to improve HAT performance (Lyons et al., 2021). This assistant can reduce the cognitive burden on the pilot and enhance operational efficiency. Ultimately, the goal of a HAT, is to regain and manage control of an aircraft mostly in the event of pilot incapacitation, either directly or by enabling intervention from a ground operator. Despite its apparent intuitiveness, the concept of mental workload remains surprisingly elusive to define conclusively, with no universal consensus reached thus far (Puca & Guglieri, 2023). The fundamental reasoning behind employing HATs is the potential to enhance performance compared to either humans working alone or machines operating independently, especially in situations characterized by significant uncertainty (Cummings, 2014). The European Union Aviation Safety Agency (EASA), the primary European aviation regulator, has outlined a valuable vision of AI and its potential impacts on aviation operations and practices. EASA's recent guidance on human-AI teaming (HAT) consists of six categories, including 1B Cognitive assistant (equivalent to advanced automation support); 2A Cooperative agent, capable of completing tasks as requested by the operator; 2B Collaborative agent, an autonomous agent that works with human colleagues, but can take initiative and execute tasks, as well as negotiate with its human counterparts (Kirwan, 2024).

Communication, coordination and trust are important in HAT (Johnson et al., 2014). To have a good communication Human – IA, there is 3 key attributes that will allow users to move toward treating automation as a teammate: a pilot-directed interface, transparency, and bi-directional communication. These principles are seamlessly integrated into all three levels of assistance offered and based on the EASA mentioned above (Shively et al., s. d.). With a focus on empowering pilots, ensuring transparency, and facilitating effective communication, our services are committed to delivering top-quality technical assistance while meeting rigorous aviation standards. Moreover, a long time ago, Fitts (1951), initiated an early effort to classify activities within air traffic control systems into human tasks and machine tasks, utilizing the "Men-Are-Better-At and Machines-Are-Better-At" (MABA-MABA) principle. However, the rigidity of this principle poses limitations, as technological advancements can render such categorizations outdated over time. Another widely adopted framework is the Level of Automation (LOA), which categorizes tasks based on cognitive abilities. For instance, LOA frameworks often include categories such as information acquisition, information analysis, decision making, and action implementation.

In recent times some works in Single Pilot Operations (SPO) have developed a Proof of Concept (PoC) of a human autonomy teaming (HAT), with cognitive computing (the machine) acting as a teammate for the pilot (the human) in SPO. The intelligent Teammate was implemented in legacy cockpits using augmented reality (AR) and vocal communication, offering two levels of assistance to test: on-request and proactive CCT "automatic" (Dormoy et al., 2021; Minaskan et al., 2022).

Various organizations, such as SESAR SJU which is an institutionalised European partnership (Save et al., 2012) and (EASA, 2023), have developed LOA taxonomies to guide the understanding and implementation of automation levels in aviation. Also, in ATCO a proof-of-concept of a controller working position (CWP) was developed and presented at the Airspace World 2023 in Geneva. It was evaluated in term of feasibility utility and usability for Single Controller Operations (SCO) in a Human-in-the-loop simulation campaign involving human ATCOs (Jameel et al., 2023). This POC was appreciated by the participants of the trade show. Nevertheless, the employment of more autonomous systems often faces issues regarding societal and organisational acceptance. Rice et al., (2019) developed a predictive model indicating that the likelihood of being willing to fly on an autonomous aircraft is positively correlated with familiarity with the technology and negatively correlated with caution toward new technologies. The main objective of Haiku project, in which the work herein presented was developed, is to enhance the understanding on Human-AI Teaming aspects, through prototypes designed to establish safe, secure, trustworthy, and effective partnerships with humans in aviation systems. Specifically in Use Case 2 (UC 2), we aim to address this gap exploring HAT for mission replanning in the cockpit of commercial aviation.

1.2 The Objective of the HAT in Commercial Aviation

It is crucial to emphasize that the objective of the proposed intelligent assistant (IA) is to assist commercial pilots in their complex task of flying. This system purpose is to improve pilots' situational awareness, reduce workload and stress associated with monitoring and mitigating unexpected events that may affect the planned route, while supporting the selection of a course of action that not only assures a safe flight termination, but also safeguards passengers' comfort and other operational objectives of the airline. Indeed, the symbiosis between man and machine lies at the heart of this technological evolution, ensuring safer and more efficient air navigation in the years ahead.

The means by which this intelligent system communicates with pilots, using operational intentions to express high-level goals, is central to these objectives. Still, different types of interactions may be proposed to promote the shared awareness, trust and coordination needed to assure the overall performance in the task. The aim of this study is to offer a comprehensive understanding of the methodology employed and the outcomes achieved during the initial validation phase of UC 2 in Haiku project, in which different intelligent assistant (IA) concepts were evaluated.

2 MATERIAL AND METHODS

2.1 Methodology

We employed the "Cognitive Walkthrough" method. Rooted in human factors engineering, this method is designed to systematically evaluate interface usability by simulating user interactions and decision-making processes iteratively using a user-centered design approach.

The initial questions that were imposed are as follows:

- What are the key features for each type of assistance (decision support - 1B, cooperative - 2A, collaborative - 2B) that enable teamwork requirements assurance and effectiveness?

Our hypothesis (H) are:

- H1: HAT cooperative teaming (2A) improves decision making process for on air re-route situation vs. decision support assistance (1B).
- H2: HAT collaborative teaming (2B) improves decision making process for on air re-route situation vs. HAT cooperative teaming (1B).

This endeavour serves to explore the potential of AI in addressing operational challenges faced by pilots, particularly in an increasingly complex aviation environment.

In our case, we evaluate three different levels of intelligent assistant.

- 1B – Human assistance
- *2A* – Human-AI cooperation,
- *2B* – Human-AI collaboration

2.2 Material

The proposed intelligent assistant concepts investigated in this paper integrate the principles of AI-based “COMBI” (Hourlier et al., 2022) in the cockpit IA with the goal of helping flight crew re-route an aircraft to a new airport destination due to deteriorating weather, considering a number of factors (e.g. remaining fuel available and distance to airport; in-route turbulences, connections possible for passenger given their ultimate destinations; etc.). The flight crew remain in charge, but always coordinates with the IA to derive the optimal solution.

Through the COMBI interface, the pilots use operational intentions to communicate with the IA. “*Intentions involve mental activities such as planning and forethought, they can be declared and clearly defined, while in other instances can be undeclared or masked, making them sometimes complex to identify*” (Bratman, 1987).

These intentions are always oriented to achieve a particular goal in a specific way.

COMBI allows the pilot to direct the options generation according to the prioritized intentions and also to assess the proposed results in terms of these intentions. In the Combi's user interface, the pilot can select and prioritize between three intentions:

- *Safety passenger comfort*
- *Pilot cognitive comfort*
- *Airline Profitability*

The graphical interface in Figure 1 was proposed to easily allow pilots selection and visualization of the prioritization of intentions.

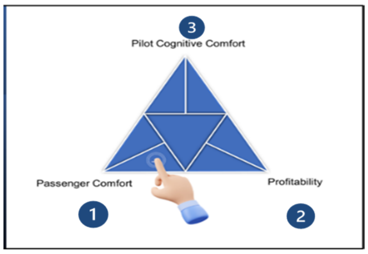

Figure 1: An interactive mock-up illustrating the communication of the pilot's intentions to the COMBI.

For example, in Figure 1, the pilot selects Passenger comfort it means that he wants a solution prioritizing the passenger comfort at first, then profitability (same side of the triangle) and at last pilot cognitive comfort.

Description of the low-fidelity prototype:

Interface showing a number of proposed routes graphically, accompanied by critical information such as weather conditions, estimated time and fuel at destination, with scores that represent how the route contributes to the three intentions.

On-demand complementary information to support operational XAI, with more elements indicating how the selected route and destination contribute to the intentions.

2.3 Use Case Scenarios

The flight scenario was designed with the assistance of two pilots and based on various Eurocontrol reports (Eurocontrol, 2023) which identify the airports most affected by significant weather conditions at different times of the year. The scenario was presented to the pilots as a brief operational flight plan, describing a regional flight from Marseille to Munich. Four different weather conditions were simulated in order to represent the four seasons, with a variety of weather representative conditions.

Pilots were asked to evaluate three different types of AI assistants along with their respective interfaces, utilizing the "Cognitive Walkthrough" method.

During the Cognitive Walkthrough sessions, pilots were presented with simulated flight scenarios and guided through tasks involving the AI assistants and interfaces. As they progressed through each interface, pilots were encouraged to articulate their thoughts, interactions, and decision-making processes out loud. Researchers closely observed and documented pilot behaviours, identifying potential usability issues, cognitive workload, and complexities within the interfaces. At the end of every level few questions about trust in AI and usability were asked.

By drawing upon the expertise and insights of seasoned pilots, the Cognitive Walkthrough methodology yields valuable feedback for refining AI assistants and interfaces within aviation settings. This structured approach enables the identification and remediation of usability challenges, ultimately improving the usability and user experience of AI technologies in aviation operations.

2.4 Modalities: Levels of Assistance

The three modalities tested with all pilots are:

- Support to decision (1B): 3 routes are proposed linked to pilot's intentions, and the associated flight plan (FP) can be implemented in FMS on request. The 3 routes maximize the first intention.
- Cooperative Assistant (2A): low-impact threats - 1 route linked to pilot's intentions, implemented on request /other cases - work same as 1B. The route maximizes the first intention.
- Collaborative assistant (2B): 2 routes are proposed - 1 called "Least negative impact", and 1 called "Best Compromise". The respective FP can be implemented in the FMS on request.

- "Least negative impact": the other intentions may lose value, but the loss will be shared as evenly as possible between the two intentions.
- "Best compromise": The loss of value for the other two intentions will be assessed against the gain on the first intention. We will accept low losses for low gains.

For each, in all the solutions proposed by the assistants, the safety is always a priority and guaranteed.

For the reroute case, the new route is always safe, ensuring that the aircraft arrives at destination with a functional machine, safe crew and minimum legal fuel. For the choice of the alternate airport, the landing with safe performance, safe machine, crew, minimum legal fuel etc are also always ensured. This information is displayed on the HMI as a grey bar to show that it is not changeable and 100%.

3 RESULTS

The panel comprised six commercial airline pilots from different nationalities selected from diverse aviation backgrounds and all flown Europe (short and long haul). The average age of the pilots is M=48.33 (SD = 6.62). On average, the pilots accumulated 9,045 flight hours throughout their careers (SD = 3.099), with an average of 535 flight hours within the last 12 months (SD = 215), reflecting variability in flight experience and recent activity among the participants. Given the small sample size of our study (6 pilots), we restricted our analyses to descriptive analysis to discern only trends. All analyses were carried out using R studio version 4.3.0.

3.1 Usefulness

With regard to the interpretation of the results for question 1 "*On a scale of 1 to 10, how useful is this assistant against being alone in the cockpit?*" with 1 "not useful at all" and 10 "really useful", distinguishing between the 3 situations and the 3 types of assistants (1B - decision support, 2A - cooperation, 2B - collaboration).

Participants responses provide valuable feedback on the perceived utility of the assistant in real-world aviation scenarios. Higher ratings indicate that the assistant is seen as more beneficial compared to operating alone in the cockpit. Conversely, lower ratings may indicate areas where the assistant falls short in meeting pilots' expectations and requirements for in-flight assistance.

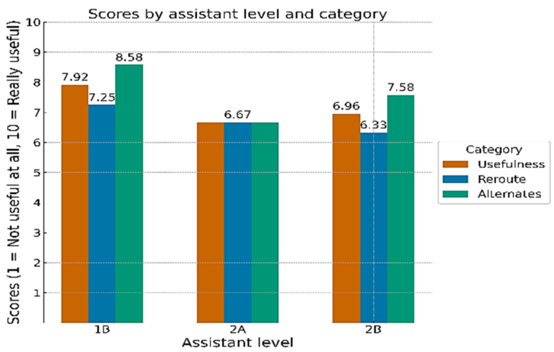

Figure 2: Overall usefulness, usefulness for reroute and usefulness for alternates (diversion), for the 3 types of assistant.

These results suggest that overall, participants tend to prefer the 1B type assistant (decision support), followed by the 2B type assistant (collaboration), while the 2A type assistant (cooperation) is less favourably rated. However, it is important to note that preferences may vary depending on specific operational situations.

Nevertheless, we can conclude that any of these assistants would be useful (score above 5), for any situation (Overall, Usefulness, Reroute, Alternates).

3.2 Usability

According to ISO 9241, the usability is the effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments.

To measure the usability, we used The Computer System Usability Questionnaire (CSUQ) which evaluate 3 dimensions : the System Usability (SYSUSE), the information quality (INFOQUAL) and the interaction quality (INTERQUAL) (Lewis, 1995).

The CSUQ is for measuring the perception of the user's experience. The pilots who participated in this study were asked to respond to the 16 CSUQ questions. The participants are asked to rate their responses in a scale from 1 "totally agree to 7 "totally disagree".

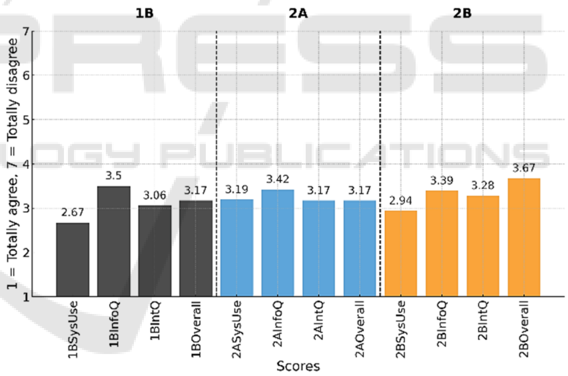

Figure 3: Results of the CSUQ questionnaire for 1B, 2A and 2B intelligent assistants, and by dimensions, SYSUSE (System Usability), INFOQUAL (Information Quality), INTERQUAL (Interaction Quality).

In summary, the cooperative (2A) and the decision support (1B) seem to offer an overall improvement in the user experience compared to the collaborative (2B). The system usability seems to be better in 1B. The information quality seems to be slightly better in 1B.

3.3 Trust in AI

This questionnaire assesses individuals' tendencies to trust technology in various contexts (Schneider & Preckel, 2017). It can be used to understand participants' attitudes and perceptions regarding the reliability, usability, and effectiveness of technology in supporting their tasks and decision-making processes.

Based on descriptive analysis, it appears that the tendencies of the results did not lead to changes in the subjects' overall trust in AI across the different conditions (Before the exhibition to the AI and after). but they seem to have an average trust in the IA (rate of 2.75 out of 5).

3.4 Interviews

In the interviews, pilots were asked about what they appreciated in the intelligent assistant concepts and what areas could be improved. Overall, the pilots appreciate the experience using a bidirectional communicator proposed by the Combi assistant, with a preference for the functionality proposed by the assistance level 1B, which offered multiple options. The operational intentions of passenger comfort and airline profitability were well understood, differently from the pilot cognitive comfort intention, which seemed more complex to assess. Despite this, pilots recognized the importance and the usefulness of intentions and positively evaluated managing the mission based on them.

The pilots also provided some recommendations to improve the interface, such as adding natural voice interaction, using colors to indicate airport situations, and offering multiple solutions like in 1B.

When asked about the best means of providing additional information to support explainability and proper oversight, pilots indicated that multiple types of interfaces and interactions should be tested in prototypes to form an opinion.

4 DISCUSSION

The difficulties encountered in understanding pilot cognitive comfort highlight the need for a training phase to thoroughly understand the model behind each intention. This will also help increase trust in the system even if the rate of trust is already good.

In our observations, we noticed differences in how decisions were made across scenarios 1B, 2A, and 2B. When using the 2A assistant, decisions were made quickly, often because there were fewer alternative options available. On the other hand, we observed that pilots took longer time to make decisions with the 2B and 1B assistants.

In scenarios where decision-making was swift, such as 2A, pilots may have been compelled to rely on rapid judgments due to the constraints of the situation. With fewer alternative options available, even if it was not the best solution for them, pilots may have accepted the option because it was just acceptable.

Conversely, in scenarios 2B and 1B, where decision times were longer due to the greater number of options, the multiple choices and the time allowed enabled the pilots to analyse, compare and evaluate the different options in depth. However, if time was limited, the limited cognitive resources under stress could have forced the pilots to adopt more cautious and deliberate decision-making processes.

Overall, the authors highlighted the impact of human cognitive limitations, particularly in high-pressure flight scenarios where time constraints may compromise the depth of analysis and lead to varied decision-making times. This variation in decision-making time can be explained by the limited cognitive resources of humans, as described in Rasmussen's SRK (Skill, Rule, Knowledge) model (Rasmussen, 1983). When relying more on analytical knowledge, the decision-making process becomes slower and more mentally demanding. This is known as the paradox of choice, where trying to avoid missing out on the best option can prolong decision-making and cause frustration over unselected options. Additionally, having multiple choices creates a need for cognitive closure, which is the desire to have a clear answer to avoid uncertainty and regret, resulting in cognitive strain and frustration. Time stress also plays a crucial role; in our scenario, the pilots had ample time to make decisions. Lower time stress allows for more analytical decision-making, leading to longer decision times.

5 CONCLUSION AND FUTURE WORKS

In this paper we showed that the different concepts of assistance have positive and negative characteristics. As future work, we will consider pilot feedback, we will continue interviewing pilots to determine the most concise comprehensible way of presenting additional information in the interface and integrate the strengths of each level into a unified assistant with personalized features. With these steps, we can enhance the utility and user experience of future projects in aviation assistance.

By incorporating pilots' feedback, we can refine the assistant's features to better suits their needs and preferences. This could involve streamlining decision-making processes, optimizing interface to ensure user acceptancy and usability, and enhancing support for handling varying levels of complexity and stress in flight scenarios.

Furthermore, merging the advantages of each level into a single assistant with a personalized touch can provide pilots with a more tailored and intuitive user experience. This approach would empower pilots to leverage the assistant's capabilities more effectively, thereby improving overall decision-making efficiency and effectiveness. A new version of combi will be tested in a simulator with more pilots.

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