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Impact of New Technologies on the Decision-Making Process of Pilots onboard Next-Generation Aircraft

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This study analyzed the influence of new technologies on the decision-making process of pilots operating Next-Generation aircrafts, focusing on how advanced automation, cockpit digitization, and the integration of intelligent software solutions have reconfigured the pilot's cognitive and operational role. An exploratory qualitative approach was adopted, based on a literature review and documentary analysis of technical and regulatory reports from bodies such as the FAA, EASA, and ICAO, as well as from aircraft manufacturers. The databases used included Google Scholar, CAPES Journals, and the ITA Library, covering publications from 2009 to 2025, a period marked by the consolidation of fly-by-wire systems, integrated digital glass cockpits, and the initial applications of embedded artificial intelligence. The results revealed that while these innovations enhance precision and operational efficiency, they also introduce new cognitive vulnerabilities, such as complacency, mode confusion, and degradation of manual skills, requiring continuous training and neurocognitive adaptation. It is concluded that next-generation aircraft represent an undeniable advancement for civil aviation, but human autonomy and supervision remain essential for operational safety. Therefore, the balance between technology and human factors should guide interface design, pilot training and certification programs, ensuring assertive decisions aligned with international regulatory principles.

Keywords: Human factors, decision-making, safety, automation, pilot training, situational awareness, artificial intelligence.

1. Introduction

The aviation sector has undergone intense transformations driven by technologies known as Next-Generation. The automation of systems, the digitization of cockpits, and the integration of intelligent software have changed how pilots interact with aircraft and make in-flight decisions. These innovations represent undeniable advances for safety and operational efficiency, but also raise new challenges related to human autonomy and the management of unforeseen situations.

Automation systems have become major allies for pilots, making an analysis of the gains and losses of this human-machine relationship essential, considering the natural limitations of both and the risk of placing the aircraft in unsafe conditions. Therefore, constant monitoring of these systems is necessary, as is the continuous development of training programs and the assessment of human piloting skills.

Automation can reduce errors but presents associated risks, such as over-reliance on systems, decreased situational awareness, and difficulty for pilots to respond quickly in emergencies. These are critical challenges related to pilot decision-making processes, where human intervention is still necessary, even though these technologies promise greater operational safety, energy efficiency, and a reduction in human error.

Given this context, a deep understanding of the interaction between human factors and technology in next-generation aircraft is imperative for additional reasons. Technological sophistication alone does not guarantee operational safety. Highly trained pilots can experience critical confusion when confronted with the degradation of automated systems, especially in high-workload and stressful situations. Scientific literature in the field of human factors in aviation has shown that automation introduces new failure modes that did not exist in conventional aircraft. The out-of-the-loop phenomenon, described by Ahlstrom (2003), illustrates how operators can lose situational awareness when automated systems assume control for prolonged periods, resulting in the degradation of the ability for manual intervention in emergencies.

Thus, the tension between technology as an ally of safety and precision versus the risk of the dehumanization of decision-making is problematized, which can compromise pilots' critical capacity in situations where human intervention is mandatory. The general objective of this study was to analyze the influence of new technologies on the decision-making process of pilots in next-generation aircraft.

2. Methodology

The methodological approach adopted for this study consists of exploratory research of a qualitative nature, based on a systematic literature review of recognized authors in the field of human factors and aviation, complemented by documentary analysis of technical and normative reports generated by the aeronautical industry and international regulatory bodies.

The search was conducted in the Google Scholar, CAPES Journals, and the ITA Library databases. The selected time frame covers the period from 2009 to 2025, marked by significant advances in civil aviation, including the consolidation of fly-by-wire systems, the expansion of glass cockpits, and the introduction of highly integrated digital human-machine interfaces.

The data collection strategy prioritized secondary sources, encompassing scientific articles published in indexed journals, technical manuals from aircraft manufacturers, normative guidelines from the International Civil Aviation Organization (ICAO) and the Federal Aviation Administration (FAA), as well as accident investigation reports produced by authorities such as the *Bureau d'Enquêtes et d'Analyses* (BEA) and the National Transportation Safety Board (NTSB).

Data analysis was conducted through thematic content categorization, as proposed by Bardin (2013). Triangulation among different sources of scientific literature, technical documentation, and case analysis to ensure the validity and reliability of the findings, minimizing interpretive biases.

3. Results

The results are presented and organized according to the main dimensions investigated in this research: (1) the identified next-generation technologies; (2) the influence of these technologies on the human aspects of decision-making; and (3) the neurocognitive bases underlying the decision-making process. Table 1 synthesizes the main findings corresponding to each of these dimensions.

Table 1. Synthesis of main research findings by thematic axis of analysis

Thematic axis	Synthesis of Results
Main technologies identified	Fly-by-Wire Glass Cockpits Adaptative automation and AI
Influence on decision-making	Neural Reorganization Altered cognitive balance Degradation of Situational Awareness Skill Degradation Mode confusion Empirical evidence
Neurocognitive bases	Dual-process theory Naturalistic decision-making Cognitive biases Multiple resource theory Mapped neural substrates

3.1. *Main technologies identified*

Three main technological categories characterize Next-Generation aircraft regarding the pilot-aircraft interface: fly-by-wire systems, glass cockpits, and adaptive automation based on artificial intelligence. These technologies represent a significant evolution from conventional aircraft, introducing new paradigms of control, information presentation to the operator, and situational awareness.

The analysis of manufacturers' technical reports and certification documents revealed that the fly-by-wire (FBW) architecture, with multiple control laws, provides robustness and safety under normal conditions but introduces significant cognitive complexity. Pilots must understand not only how to operate in each mode, but also which conditions trigger transitions between modes, which protections remain active, and how to adapt piloting techniques, resulting in a potential source of operational confusion, especially in high-workload or stressful situations.

The evolution of embedded technology is now entering the era of adaptive automation and artificial intelligence. The analysis of regulatory documents (EASA 2023; FAA 2023; Prinzel et al. 2024) reveals concern with the development of systems that autonomously adjust their behavior based on operational context and operator state. Emerging applications include intelligent crew assistants that monitor operations and suggest courses of action, intelligent failure diagnostics based on machine learning, real-time trajectory optimization, collision prevention with conflict prediction, and pilot monitoring for the detection of fatigue, distraction, or incapacitation.

Prinzel et al. (2024) emphasize that the effective integration of AI requires a paradigm shift, from automation as a tool to human–AI teaming, where the AI acts as a team member. This demands transparency and easy understanding of the machine's reasoning, proper calibration of pilots' trust, clear authority distribution (keeping critical decision-making under human responsibility), intuitive interfaces with natural modalities such as language or voice commands, and graceful degradation when the system encounters situations outside its training envelope.

The synthesis of these findings allows us to characterize Next-Generation aircraft as complex sociotechnical systems, where computational mediation permeates all operational dimensions: physical control of the aircraft (fly-by-wire), presentation and interpretation of information (glass cockpits), and decision-making support (artificial intelligence). This mediation expands operational capabilities and introduces safety protections but, simultaneously, increases cognitive complexity, reduces direct sensory feedback, and creates new failure modes non-existent in conventional aircraft.

3.2 *Influence of technologies on human aspects of decision-making*

The analysis revealed multiple dimensions through which next-generation technologies influence pilot decision-making processes. These influences manifest at both a fundamental neurocognitive level and an observable operational behavior level, with significant implications for flight safety.

When pilots operate extensively in supervisory mode, neural patterns become optimized for this type of processing. Sudden transitions to active manual control, especially during emergencies, require rapid reconfiguration of neural activation that may not occur instantly, potentially degrading initial performance during a critical period.

A second dimension of influence relates to the modification of the balance between System 1 and System 2 cognitive processing. The dual-process theory (Kahneman 2011), extensively documented in the reviewed literature, establishes that human decisions result from the interaction between System 1 (fast, automatic, intuitive, based on heuristics) and System 2 (slow, deliberate, analytical, cognitively costly). Traditional aeronautical expertise is largely grounded in System 1, where thousands of hours of practice allow for rapid pattern recognition and appropriate responses without extensive conscious deliberation (Klein 1998; Orasanu and Fischer 1997).

Advanced automation fundamentally alters this balance. Tasks that previously required active execution and conscious attention (System 2) are assumed by automation, allowing them to become background processes (System 1), freeing cognitive resources for higher-level supervision. However, when automation behaves unexpectedly or fails, pilots must quickly re-engage System 2 for diagnosis and intervention (Ahlstrom 2003). This transition can be difficult, especially if the pilot was in a state of low vigilance. Additionally, System 1, although efficient, is vulnerable to systematic biases, such as confirmation, availability, and anchoring, which can compromise judgment in non-routine situations (Tversky and Kahneman 1973).

A third dimension of influence refers to the degradation of situational awareness through multiple mechanisms. Endsley's (1995) three-level model—perception, comprehension, and projection—provides the framework for analysis. Automation can degrade perception (Level 1) when pilots, trusting automated systems, reduce vigilance in scanning instruments and the external environment. It can degrade comprehension (Level 2) when opaque interfaces do not clearly communicate what the system is doing or why, hindering the construction of an accurate mental model. It can further degrade projection (Level 3) when dependence on automation reduces the mental practice of anticipating future developments.

A fourth identified dimension of influence relates to the degradation of cognitive and motor skills through the irony of automation (Bainbridge 1983). When automation assumes routine tasks, pilots lose opportunities for practice that maintain consolidated cognitive and sensorimotor schemas. Consequently, when automation failure requires manual intervention, pilots may be unprepared, with degraded skills.

A fifth dimension of influence relates to the phenomenon of mode confusion, in which pilots develop an incorrect mental model of which automation mode is active, resulting in inappropriate expectations about system behavior and potentially inappropriate control inputs (Casner and Schooler 2014). The proliferation of modes in modern FBW and flight management systems, combined with automatic transitions between modes that may not be immediately salient, creates an environment conducive to confusion. Interfaces that do not clearly communicate the automation's current state exacerbate the problem.

Thus, while next-generation technologies offer expanded operational capabilities and safety protections, they fundamentally alter the nature of the piloting task from active execution to supervision of complex systems. These changes cause profound neurocognitive and behavioral implications that create new vulnerabilities that are not present in conventional aircraft.

3.3 *Neurocognitive bases*

The analysis of the neuroscience literature allowed for the mapping of neural substrates and cognitive processes underlying decision-making in highly complex aeronautical environments. The findings reveal dual cognitive architecture, systematic vulnerabilities, and expertise mechanisms that explain both successful and failed decisions documented in real-world operations.

Kahneman's (2011) dual-process theory emerges as a central integrative framework. System 1—fast, automatic, associative, parallel, unconscious, requiring minimal effort—grounds aeronautical expertise through rapid recognition of patterns consolidated by extensive experience. System 2—slow, deliberate, rule-based, serial, conscious, requiring significant cognitive efforts recruited for non-routine situations, complex problem analysis, and critical supervision of System 1 outputs.

The literature on naturalistic decision-making (Klein 1998; Orasanu and Fischer 1997) documents that experts rarely generate and compare multiple options exhaustively. Instead, they use the recognition-primed decision (RPD) model: they recognize the situation as typical based on experience (System 1), generate the first option that comes to mind, mentally simulate its execution (System 2), and implement it if the simulation reveals no problems. This efficient integration of intuitive and analytical processing characterizes expertise but reveals a vulnerability: if the situation does not match previously experienced patterns, System 1 may fail to recognize it appropriately, generating a quick but inadequate decision.

The analysis of the literature on cognitive biases (Tversky and Kahneman 1973; Kahneman 2011) reveals systematic vulnerabilities of System 1 relevant to aeronautical operations. Confirmation bias leads pilots to interpret ambiguous information consistently with initial expectations, potentially ignoring critical contradictory evidence. The availability bias causes recent or vivid events to be judged more likely than they are, distorting risk perception. Anchoring bias causes excessive reliance on the first information received, even when subsequent data suggests a different interpretation. These biases, products of generally efficient cognitive heuristics, become problematic in atypical situations where intuition can be misleading.

Wickens' (2008) multiple resource theory provides a framework for understanding attentional capacity limitations. Attentional resources are divided into separate pools by sensory modality (visual versus auditory), processing code (spatial versus verbal), and processing stage (perception versus response). Tasks competing for resources from the same pool interfere with each other more than tasks using different pools. In modern cockpits with multiple dense visual displays, competition for limited visual-spatial resources can result in attentional tunneling (excessive focus on one source to the detriment of others) or task shedding (abandoning lower-priority tasks to maintain performance on critical tasks).

The synthesis of these findings reveals a complex cognitive architecture in which aeronautical decisions result from the dynamic interaction between multiple neural systems and cognitive processes, each with specific capabilities and characteristic vulnerabilities. Understanding this architecture is essential for designing technologies that amplify human capabilities while compensating for limitations, and for developing training that strengthens both System 1 (through extensive practice) and System 2 (through exposure to scenarios requiring deliberate analysis), as well as the metacognition that enables recognition of when to transition between systems.

3.4 *Training recommendations*

The first recommendation relates to adaptive cognitive training. Studies (Casner and Schooler 2014; Helmreich et al. 1999; Endsley 2017) converge on the need for training that transcends standardized procedures by incorporating realistic simulations of automation failures, mode confusion scenarios, transitions between control laws, and ambiguous situations where presented information may be degraded. Training progression should follow a logic of increasing complexity, culminating in highly dynamic scenarios with multiple simultaneous failures that challenge prioritization and cognitive load management. The objective is not only to develop memorized procedural responses but to practice the deliberate transition between System 1 and System 2, maintaining the cognitive flexibility required for unanticipated situations.

A second category relates to the development of metacognition and awareness of cognitive biases. The literature (Kahneman 2011; Orasanu and Fischer 1997; Wickens 2008) emphasizes that pilots must develop awareness of their own decision-making processes and sensitivity to recognize when conscious deliberation is necessary. This requires structured cognitive debriefings where instructors conduct retrospective analysis of decisions, identifying moments when biases influenced judgment. Specific bias recognition exercises, where scenarios deliberately induce predictable biases followed by reflective discussion, can develop metacognitive sensitivity.

A third category relates to maintaining manual flying proficiency and managing system degradation. The irony of automation (Bainbridge 1983) and empirical evidence of skill degradation (Casner and Schooler 2014) establish the imperative need for regular exposure to manual flight without automated protections, including stall recovery, unusual attitudes, and management of multiple failures. The practice frequency must be sufficient to maintain consolidated sensorimotor and cognitive schemas. Training must explicitly address transitions between FBW control laws, ensuring a deep understanding of the implications of each mode (Ahlstrom 2003).

A fourth category refers to preparation for human–AI interaction and adaptive automation. Emerging literature (Prinzel et al. 2024; Parasuraman and Riley 1997; Gunning and Aha 2019) establishes that effective human–AI teaming requires appropriate trust calibration, an understanding of the capabilities and limitations of machine learning systems, familiarity with explainability interfaces, and the ability to manage rapid transitions between assisted operation and manual control when the system encounters limitations.

A fifth category emphasizes human-centered design principles and manufacturer–operator cooperation. Technical literature (Yeh et al. 2013; EASA 2023; FAA 2023) establishes that the effectiveness of training critically depends on system design quality. Fundamental principles include stimulus–response compatibility, sensory redundancy, clear visual hierarchy, minimization of clutter, immediate feedback, and transparency of the automation state. For AI-based systems, explainability is a fundamental requirement. Cooperation between manufacturers and operators during development allows operational pilots to provide feedback on usability and potential vulnerabilities.

A sixth category refers to continuous competency assessment and program adaptation. ICAO documents (2018) on evidence-based training establish that training must be a continuous process, not a single event, incorporating systematic monitoring of operational events, analysis of recurring patterns indicative of deficiencies, assessment of higher-order cognitive skills (not just procedural verification), and regular updating of programs based on lessons learned. Frameworks such as HFACS (Wiegmann and Shappell 2003), LOSA, and TEM (Helmreich et al. 1999) provide structured methodologies for performance observation and analysis.

3.5 Discussion

The discussion of this research's findings consolidates that the introduction of new technologies in Next-Generation aircraft represents undeniable advances for aviation in terms of safety, operational efficiency, and precision; however, the centrality of the human element remains unquestionable in the decision-making context.

An important element to consider is ICAO's Next Generation of Aviation Professionals (NGAP), in which the growing use of automation and the incorporation of AI in the air navigation system establish a common understanding of automation levels. The nature of the decision to be supported will determine the necessary level of automation (ICAO 2016).

To ensure that the use of artificial intelligence is beneficial, ICAO points to the adoption of principles established by the United Nations, which can be adapted to guide the use of AI in the air navigation system involving pilots, in an ethical manner aligned with the fundamental values of human rights, promoting peace and sustainable development (UN 2021). Among the proposed principles are: 1) do no harm; 2) defined purpose, necessity, and proportionality; 3) fairness and non-discrimination; 4) sustainability; 5) right to privacy, data protection, and governance; 6) human autonomy and oversight; 7) transparency and explainability; 8) accountability; and 9) inclusion and participation.

Furthermore, this study reveals that these technologies enhance the precision and reliability of decisions under normal operating conditions, but also create new cognitive and operational demands, especially in scenarios of anomalies, systemic failures, or degradation of automation modes. It is in these moments that the pilot is challenged to engage the analytical system and critically assess displayed data to increase decision-making assertiveness (Kahneman 2011).

Thus, it is possible to affirm that the impact of new technologies is not limited to operational improvement, but involves a deep understanding of the human element, requiring, at all levels, continuous preparation, institutional adaptation, and the development of refined cognitive competencies in an increasingly complex, digitalized, and interdependent operational environment.

4. Conclusion

This study analyzed the influence of embedded technologies in Next-Generation aircraft on the pilots' decision-making process, demonstrating that advanced automation represents a milestone in the evolution of civil aviation, enhancing precision and operational efficiency. However, the results reveal that these innovations also profoundly reconfigure the pilot's cognitive role, shifting from active executor to supervisor of complex systems—a role that demands new competencies, constant vigilance, and metacognition.

It is concluded that the future of safe and efficient aviation depends not only on technological sophistication but on the ethical, cognitive, and operational integration between man and machine. Preserving human autonomy, vigilance, and adaptability constitutes the main challenge and also the greatest differentiator in the era of digital aircraft.

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