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COGNITIVE FATIGUE AND INFORMATION OVERLOAD IN THE DIGITAL COCKPIT: MITIGATING EMERGING HUMAN PERFORMANCE RISKS

(Presented by Saudi Arabia)

EXECUTIVE SUMMARY

This paper addresses the emerging human performance risks associated with the digital transformation of the modern flight deck. While digital systems such as electronic flight bags (EFBs), real-time data-links, and advanced automation have significantly enhanced flight safety and efficiency, they have also introduced new challenges related to information overload, shifting pilot tasks, and increasing cognitive integration demands. The continuous monitoring and processing of high-volume, dynamic digital inputs can degrade pilot decision-making, impair situational awareness, and compromise flight safety, particularly during high-workload or abnormal phases of flight.

These risks are outlined in the *Human Performance Manual* (Doc 10151) as cognitive limitations described under section 1.4, human performance principles of this manual. However, they are not yet comprehensively addressed in existing ICAO Standards and Recommended Practices (SARPs) or guidance material. A proactive, human-centered design approach is required to ensure that technological advancement continues to support, rather than hinder, human performance.

This paper proposes that ICAO take a leading role in developing a global framework to mitigate these risks. This includes developing new guidance material, updating training requirements, and amending relevant ICAO Annexes and Assembly Resolutions to ensure the safe integration of digital technologies into the cockpit.

Action: The Assembly is invited to:

- acknowledge the safety risks associated with cognitive limitations, information overload, and altered task demands in modern digital cockpits;
- direct the Council to initiate a comprehensive review of the human performance implications of data-intensive into flight deck environments;
- support the development of new guidance material on human-centered design and the amendment of relevant SARPs and policies to address these emerging challenges; and
- adopt the proposed amendment to Assembly Resolution A41-10, Appendix O, as detailed in the attachment to this paper.

<i>Strategic Goals:</i>	This working paper relates to <i>Every Flight is Safe and Secure</i> , and <i>Aviation Delivers Seamless, Accessible, and Reliable Mobility for All</i> .
<i>Financial implications:</i>	Activities to be undertaken within the regular budget.

<i>References:</i>	Annex 1 — <i>Personnel Licensing</i> Annex 6 — <i>Operation of Aircraft</i> Annex 19 – <i>Safety Management</i> Doc 10151, <i>Human Performance (HP) Manual for Regulators</i> Doc 9683, <i>Human Factors Training Manual</i>
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1. INTRODUCTION

1.1 The digital transformation of aviation has generated substantial improvements in safety, operational efficiency, and information accessibility. Modern flight decks feature a suite of powerful digital tools, including electronic flight bags (EFBs) with performance management applications, controller-pilot data link communications (CPDLC), and real-time weather and traffic information systems. These advancements have fundamentally enhanced flight crew situational awareness and automated certain manual tasks, contributing to a safer global aviation system.

1.2 However, this proliferation of digital information also introduces new and complex human factors challenges. The modern cockpit environment demands that pilots continuously monitor, process, and integrate high volumes of dynamic digital inputs from multiple systems and platforms. Certain studies on cockpit workload have shown, automation does not simply eliminate tasks but often shifts them, creating new monitoring and cognitive integration responsibilities. This constant cognitive demand creates a risk of information overload and cognitive fatigue and limitations, which can impair attention management, degrade decision-making, and increase the likelihood of operational errors, particularly during critical, high-workload phases of flight.

1.3 Emerging human performance risks associated with digital complexity are partially covered through the Software, Hardware, Environment, Liveware (SHELL) model, where the Liveware-Software interface that represents delays and errors may occur while seeking vital information from confusing, misleading, or excessively cluttered documentation and charts. Problems can also be related to the presentation of information and the design of computer software. However, cognitive fatigue risks will need to be clearly addressed and mitigated with relation to the Liveware-Software interface as well. As outlined in the *Human Performance Manual* (Doc 10151), the current guidance on human factors, certification standards, and training curricula should evolve to incorporate human-centered design (HCD) principles, addressing the unique challenges posed by the data-intensive digital cockpit.

1.4 The purpose of this paper is to highlight the safety implications of cognitive limitations and information overload in the digital cockpit and to propose a proactive, human-centered strategy for their mitigation. By addressing these challenges, the global aviation community can ensure that the integration of new technologies continues to enhance, rather than compromise, flight safety.

2. DISCUSSION

2.1 The data-intensive flight deck

2.1.1 The modern flight deck has evolved from an environment of information scarcity to one of information abundance. Pilots are interacting with a vast array of digital systems, including:

- a) *Advanced flight management systems (FMS)*: providing complex routing, performance, and navigation data;
- b) *Electronic flight bags (EFBs)*: hosting several applications, from performance calculators and electronic charts to real-time weather overlays and aircraft operators' messaging;
- c) *Data link communications*: including CPDLC and Aircraft Communications Addressing and Reporting System (ACARS), which require continuous monitoring and text-based interaction; and
- d) *Automated decision aids*: which, while beneficial, require careful oversight and understanding by the flight crew to ensure their outputs are appropriate for the operational context.

2.1.2 The cumulative effect of these systems is a significant increase in the cognitive load placed on flight crews. Unlike the static information presented in traditional cockpits, digital data is often dynamic, continuously updated, and presented across multiple displays, requiring pilots to actively manage their attention and filter for relevance and perform significant cognitive integration. Certain studies have demonstrated that such environments can alter intra-crew communication and workload distribution, reinforcing the need to analyse the flight deck as an integrated system rather than a collection of separate tools.

2.2 Human performance and safety risks

2.2.1 The increased cognitive demands of the digital cockpit directly impact human performance, introducing risks that can erode safety margins. These risks are covered by the Human Performance Principles outlined in Doc 10151, particularly HP Principle 1: People's performance is shaped by their capabilities and limitations. These limitations can be summarized as follows:

- a) *Information overload*. When the volume of incoming information exceeds a pilot's capacity to process it, critical alerts may be missed, situational awareness can become fragmented, and decision-making can be delayed or degraded. This risk is amplified during abnormal situations, where an influx of system alerts can overwhelm the flight crew.
- b) *Cognitive fatigue*. The sustained mental effort required to manage a data-rich environment can lead to cognitive fatigue, characterized by reduced vigilance, impaired short-term memory, and a decreased ability to perform complex problem-solving. This fatigue is distinct from physical tiredness and can develop even on short-haul flights with high operational complexity.
- c) *Attentional tunnelling*. To manage high cognitive load, pilots may focus on a single information source or task to the exclusion of other critical data, such as a changing weather picture or a deviation from the desired flight path.
- d) *Degradation of manual flying skills*. Over-reliance on automation and digital decision aids, coupled with a complex human-machine interface, may lead to an erosion of

fundamental manual flying and problem-solving skills, which are critical during unforeseen events or automation failures.

2.3 Gaps in the current regulatory framework

2.3.1 While ICAO has established a robust framework for human performance and safety management, the following gaps concerning the challenges of the digital cockpit need to be addressed:

- a) *Human Factors Guidance*. Existing guidance material, while excellent, does not yet fully incorporate details on human-centred design of data-rich systems or provide comprehensive strategies for managing cognitive load in a digital environment and for designing integrated, human-centred systems.
- b) *Certification Standards*. Aircraft and avionics certification processes in Annex 8 focus primarily on system integrity and functionality. They do not consistently assess the cumulative cognitive impact of multiple, interconnected digital systems on the flight crew's performance in a realistic operational context.
- c) *Training and Licensing*. Competency-based training and assessment frameworks, including evidence-based training (EBT), must be updated to include specific competencies and scenarios related to digital information management, attention switching, and recognizing the symptoms of cognitive fatigue.
- d) *Safety Management*. The risks associated with information overload and cognitive fatigue are emerging hazards that must be explicitly integrated into State Safety Programmes (SSPs) and operators' Safety Management Systems (SMS) under Annex 19, ensuring they are subject to formal hazard identification and safety risk management.

3. CONCLUSION

3.1 The continued digitalization of the flight deck is vital for the future and modernization of air navigation. However, it is imperative that this technological progress is accompanied by a parallel evolution in the understanding and mitigation of the associated human performance risks.

3.2 A proactive and coordinated global effort, led by ICAO, is necessary to develop human-centered solutions that ensure pilots can effectively manage the data-rich cockpit environment. This includes updating design concepts to align with human-centered design (HCD) principles, enhancing training methodologies, and modernizing regulatory oversight to place human performance at the center of technological integration.

3.3 By taking action, the Assembly can ensure long-term safety, resilience, and sustainability of the global aviation system as it continues its digital evolution. Therefore, the Assembly can direct the Council to task the Secretariat, in coordination with relevant technical panels, to:

- a) develop comprehensive guidance material on human-centered design methodologies for flight deck systems and interfaces to mitigate information overload and support effective cognitive load management;

- b) review existing SARPs in Annex 1, Annex 6, Annex 8, and Annex 19 and, where necessary, develop amendments to ensure that the risks associated with the digital cockpit environment are appropriately managed through certification, operations, training, and safety management; and
- c) promote research and operational performance studies into effective strategies and technologies for monitoring and mitigating cognitive fatigue and managing complex automation in flight operations.

3.4 The Assembly can also urge Member States to incorporate principles of digital information management and cognitive fatigue mitigation into their national pilot training programmes, certification processes, and safety oversight activities. To this end, a proposal for amendment to Assembly Resolution A41-10, Appendix O, is provided in the attachment to formalize ICAO's continuing policy in this critical area.

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APPENDIX

PROPOSAL FOR AMENDMENT TO ASSEMBLY RESOLUTION A41-10

Whereas the aims and objectives of ICAO as laid down by the Chicago Convention provide for fostering the development of international air transport “. . . so as to . . . promote safety of flight in international air navigation”;

Whereas it is recognized that human performance, as influenced by physiological and cognitive capabilities and constraints, contributes significantly to the overall safety performance of the aviation system;

Whereas it is recognized that the safety and efficiency benefits associated with new technologies, systems and procedures can only be realized when they are designed to enhance the performance of the individuals who use them; and

Whereas it is recognized that implementation of the future aviation systems will result in changes in roles for aviation professionals requiring work across multidisciplinary teams to support collaborative decision-making;

The Assembly resolves that:

1. Member States ensure the integration of human performance considerations in the planning, design, and implementation of new technologies, systems and processes as part of a safety management approach;
2. Member States promote and facilitate the integration of human performance elements within competency-based training programmes throughout the career of a professional; and
3. Member States include strategies which promote safe, consistent, efficient and effective operational performance of the individual and across teams of individuals to address safety priorities.
4. Member States and ICAO should promote safety in an increasingly digital flight deck environment by addressing the human performance implications of data-intensive systems, including by:
 - a) fostering human-centered design principles for flight deck systems and interfaces that mitigate information overload and prevent cognitive fatigue;
 - b) ensuring that pilot training and competency frameworks, including Evidence-Based Training, incorporate the skills required to manage complex digital information effectively and mitigate automation-related risks; and
 - c) encouraging the integration of risks associated with human-machine interaction and cognitive load into State Safety Programmes and operators' Safety Management Systems.

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