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From task-based training to human-automation supervision: the evolution of pilot training in commercial aviation

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Abstract

Pilot training in global commercial aviation has undergone a profound transformation since the early 2000s, evolving from traditional task-based approaches to competency-based and evidence-driven frameworks. This study examines this transition through the lenses of operational safety, automation, and human factors, with emphasis on the 2020–2026 period and projections toward 2040. Based on data from the International Civil Aviation Organization (ICAO) and the International Air Transport Association (IATA), a sustained reduction in accident rates is observed, reaching 1.32 accidents per million sectors in 2025, while risks related to human–automation interaction continue to emerge. Challenges such as the monitoring problem, automation surprise, loss of mode awareness, and automation complacency are analyzed as critical factors affecting performance in highly automated environments. The findings show that the integration of Competency-Based Training and Assessment (CBTA) and Evidence-Based Training (EBT) has become the global standard, enabling pilots to effectively supervise complex systems. The increasing incorporation of artificial intelligence introduces new operational demands, particularly in cognitive resilience and management of non-deterministic systems. By 2040, pilot training is expected to balance technical proficiency, human–AI collaboration, and preservation of human authority in safety-critical decision-making.

Keywords: pilot training; CBTA; Evidence-Based Training; aviation automation; human factors; artificial intelligence; operational safety; cognitive resilience

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Introduction

Global commercial aviation has established itself as the safest mode of transportation in history, the result of the integration of technological advances, rigorous regulation, safety management systems, and the continuous evolution of pilot training. Since the early 2000s, the industry has recorded a consistent reduction in accident rates, driven by proactive strategies that prioritize human factors, automation, and data-driven training.

According to the IATA Annual Safety Report 2025, the global accident rate reached 1.32 per million sectors in 2025, within a universe of approximately 38.7 million flights. Although annual variations occur, the long-term trend shows significant gains in operational safety, reflecting systemic improvements across multiple dimensions of aviation.

In this context, pilot training emerges as one of the central pillars of safety, keeping pace with the growing complexity of aeronautical systems and the intensification of automation. The transition from traditional task-based models to competency-based and evidence-based approaches represents a paradigm shift aligned with contemporary operational demands.

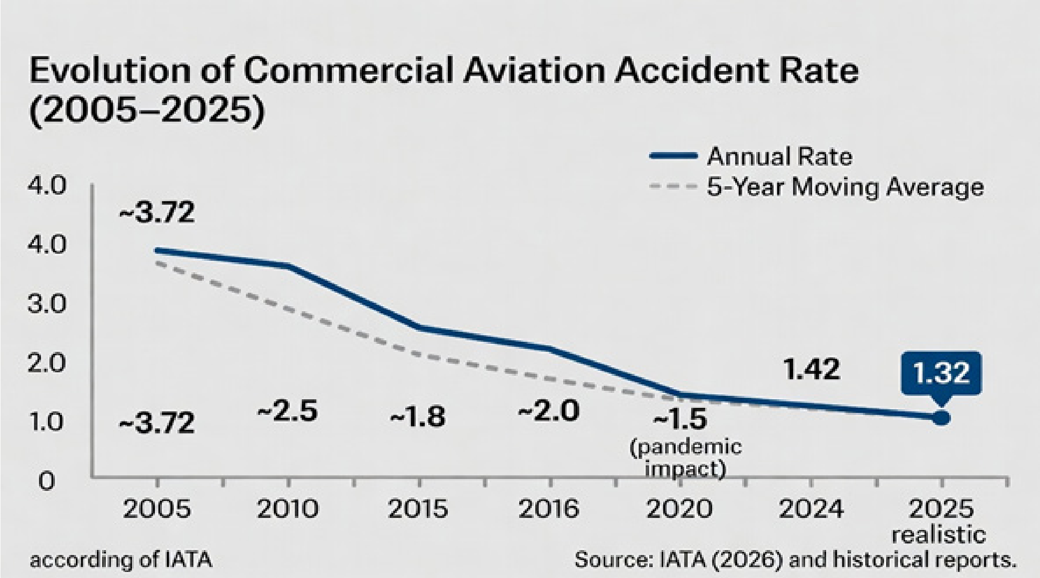
This article analyzes this evolution from the perspective of operational safety, human-automation interaction, and human factors, with a focus on the period from 2020 to 2026 and projections until 2040.

Operational safety and global statistics

Operational safety in commercial aviation is systematically monitored by organizations such as IATA and ICAO, which aggregate global data to identify trends and guide improvement actions. The IATA Annual Safety Report 2025 reveals that the industry carried approximately 5 billion passengers on 38.7 million flights, recording an accident rate of 1.32 per million sectors — higher than 2024 performance (1.42), but slightly above the five-year moving average (1.27). Of the 51 accidents that occurred, eight were fatal, resulting in 394 onboard fatalities. IOSA-certified operators showed superior performance (0.98 accidents per million sectors) compared to non-certified ones (2.55), highlighting the value of standardized audits.[1]

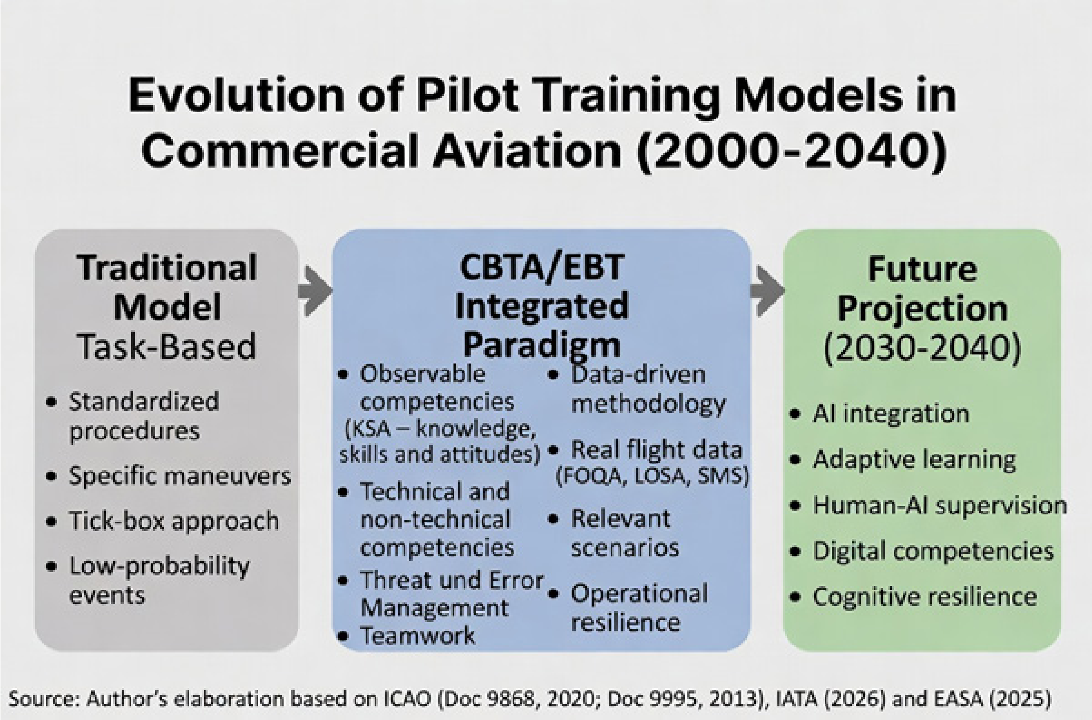
The ICAO Safety Report 2025 Edition complements these data, indicating a global rate of 2.56 accidents per million departures in 2024 (a 36.8% increase from 2023, but below 2019 levels), with

95 accidents, 10 fatal, and 296 fatalities, in passenger traffic that reached 4.528 billion — surpassing pre-pandemic levels. The long-term reduction in accidents reflects advances in Safety Management Systems (SMS), technology, and training. Human factors remain responsible for approximately 70-80% of operational events,[2,3] reinforcing the need for training that integrally addresses complacency, fatigue, and interaction with automated systems. By 2040, in the face of projected air traffic growth, maintaining low rates will depend on the effective integration between artificial intelligence and adaptive training.


Evolution of Commercial Aviation Accident Rate (2005–2025)

according of IATA
Source: IATA (2026) and historical reports.

Figure 1 Evolution of the accident rate in commercial aviation according to IATA (2005–2025). A sustained long-term reduction trend is observed, with the annual rate falling significantly since the 2000s to 1.32 in 2025, and the five-year moving average reaching 1.27 in 2025. Source: IATA (2026) and historical reports.

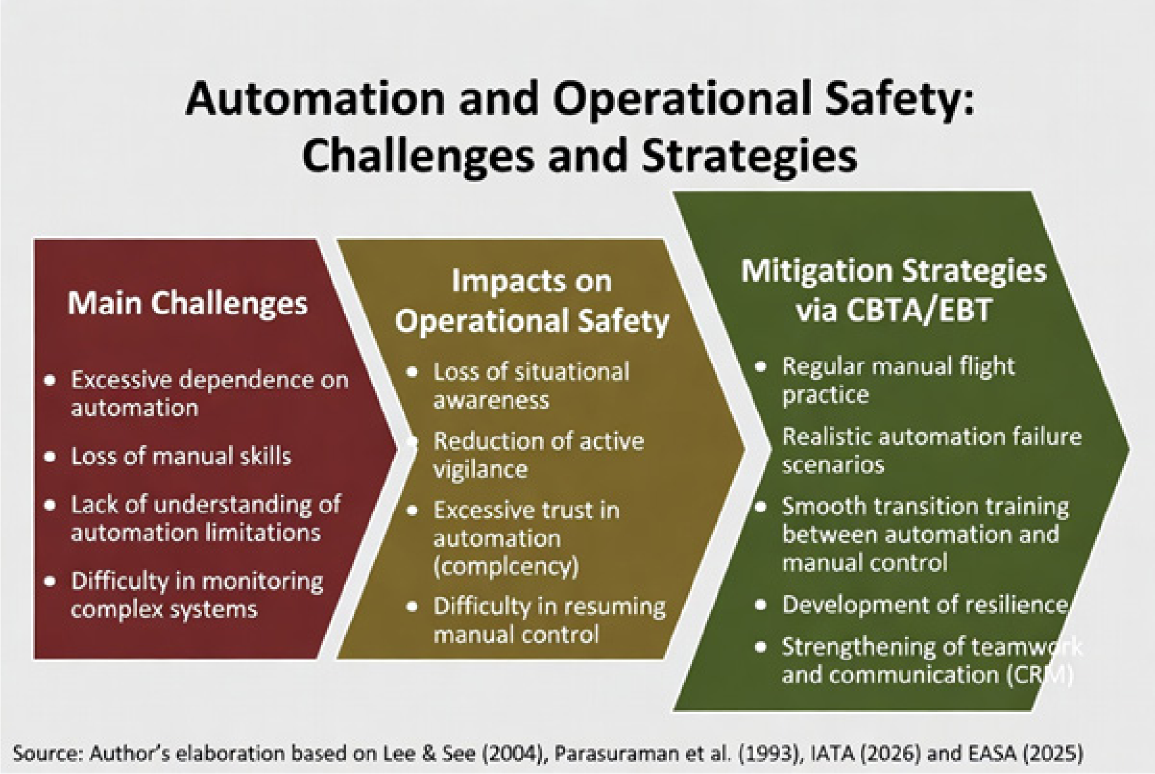

Evolution of Pilot Training Models in Commercial Aviation (2000-2040)

Source: Author's elaboration based on ICAO (Doc 9868, 2020; Doc 9995, 2013), IATA (2026) and EASA (2025)

Figure 2 Evolution of pilot training models in commercial aviation (2000–2040): transition from the traditional task-based model to the competency- and evidence-centered paradigm (CBTA/EBT) and the future projection with artificial intelligence integration. Source: Author's elaboration based on ICAO (Doc 9868, 2020; Doc 9995, 2013), IATA (2026) and EASA (2025).

Source: Author's elaboration

Figure 3 Evolution of cockpits in commercial aviation: from the traditional analog panel (2000s) to the modern glass cockpit (2020-2026) and the smart cockpit with AI integration (projection for 2040). Source: Author's elaboration.



Automation and Operational Safety: Challenges and Strategies

Main Challenges

- Excessive dependence on automation
- Loss of manual skills
- Lack of understanding of automation limitations
- Difficulty in monitoring complex systems

Impacts on Operational Safety

- Loss of situational awareness
- Reduction of active vigilance
- Excessive trust in automation (complcency)
- Difficulty in resuming manual control

Mitigation Strategies via CBTA/EBT

- Regular manual flight practice
- Realistic automation failure scenarios
- Smooth transition training between automation and manual control
- Development of resilience
- Strengthening of teamwork and communication (CRM)

Source: Author's elaboration based on Lee & See (2004), Parasuraman et al. (1993), IATA (2026) and EASA (2025)

Figure 4 Challenges of human-automation interaction, impacts on operational safety, and mitigation strategies through the CBTA/EBT model. Source: Author's elaboration based on Lee & See (2004), Parasuraman et al. (1993), IATA (2026) and EASA (2025).

Evolution of training models

Since the early 2000s, pilot training models in commercial aviation have undergone a profound transformation, moving from traditional task-based approaches-centered on standardized procedure lists, specific maneuvers, and low-probability events - to more sophisticated and effective models anchored in competencies and evidence. This transition reflects the need to prepare pilots to operate in increasingly complex environments, marked by advanced automation and the variability of operational threats.

Competency-Based Training and Assessment (CBTA) constitutes the central paradigm of this evolution by prioritizing the development and assessment of observable and measurable competencies, understood as integrated combinations of knowledge, skills, and attitudes (KSA) essential for safe and effective performance.[4] Complementarily, Evidence-Based Training (EBT) functions as an operational methodology that uses real flight data - from FOQA, LOSA, incident reports, and Safety Management Systems — to define training priorities, replacing generic and mechanical training with relevant, data-driven scenarios. While CBTA establishes what must be developed (technical and non-technical competencies, with emphasis on Threat and Error Management, workload management, situational awareness, and teamwork), EBT determines how and with what focus the training should be conducted, promoting greater operational resilience and better transfer of learning to the real flight context. This synergistic integration has allowed a consistent evolution from the traditional model to adaptive approaches that are more effective in mitigating risks associated with human factors and increasing automation.

International regulators have responded to this transformation in different ways. EASA has progressively incorporated EBT since 2016, established the baseline in 2020, and advanced with CBTA rulemaking in 2022. The FAA, in turn, maintains the Advanced Qualification Program (AQP) as its main framework and is conducting, in 2026, a comparative study on full CBTA adoption, motivated by concerns regarding transition costs, standardization, and safety equivalence. Globally, approximately 75% of national regulators already allow some form of CBTA, covering authorities in Europe, Asia-Pacific, the Middle East, and Latin America. IATA and ICAO strongly recommend the integrated adoption of CBTA/EBT throughout the pilot's career - from ab initio training to type rating, recurrent training, and upgrade to command. Manufacturers such as Boeing and Airbus have incorporated these models into their programs since 2014-2020, with more than 70 airlines in advanced transition phases in 2025-2026.

Empirical studies indicate that the implementation of CBTA/EBT has generated a significant reduction in the need for remedial training and measurable improvement in operational performance.[4,5] However, challenges persist, such as consistent instructor calibration (ORCA process: Observe, Record, Classify, Assess), the high initial cost of operational data infrastructure, global standardization of competency metrics, and adaptation to different organizational cultures. Despite these difficulties, the model demonstrates proven effectiveness in improving resilience to automation failures and reducing events related to human factors.

For the 2025-2030 horizon, the complete digitalization of simulators with adaptive artificial intelligence learning is expected, as well as the integration of digital competencies, such as data literacy and human-AI collaboration. By 2040, curricula should balance technical mastery, supervision of autonomous systems, and literacy in intelligent technologies, consolidating CBTA/EBT as the global norm.

Automation and transformation of the pilot's role

Automation has redefined the pilot's role, shifting from direct command controller to supervisor of complex systems. In fly-by-wire aircraft with advanced Flight Management System (FMS), automation significantly reduces workload during cruise, but alters the pilot's active engagement, who now monitors rather than actively flies. This change can generate complacency and erosion of manual skills. Although high levels of automation improve performance in routine tasks, studies indicate reduced active vigilance and situational awareness.[6,7]

The contemporary pilot primarily acts as an automation manager, requiring deep understanding of system limitations and continuous maintenance of vigilance. Current training programs incorporate regular manual flight and failure scenarios to preserve psychomotor competencies. In 2025-2026, next-generation cockpits reinforce this supervisory role, although IATA and ICAO reports indicate that complacency still contributes to 70-80% of events involving human factors. By 2040, with the advancement of AI, the pilot will supervise partially autonomous systems while retaining final responsibility for safety. This transition requires a delicate balance between calibrated trust and the capacity for timely intervention.

Limitations of human-automation interaction: monitoring problem, automation surprise, and mode awareness

Among the main challenges of automation are the monitoring problem (difficulty in sustaining prolonged vigilance in highly reliable systems), automation surprise (unexpected reactions that provoke the startle effect), and loss of mode awareness (lack of knowledge or confusion regarding the active modes of the autopilot or autothrust). These phenomena contribute to systematic errors, especially in undetected disconnections or inadequate mode selection.

Deficiencies in mode understanding frequently interact with complacency, aggravating detection failures. Mitigation strategies include specific training on interfaces, provision of clear feedback, and repeated practice of transitions. In future systems based on non-deterministic AI, the risk of surprise tends to increase, making greater algorithmic transparency and the development of cognitive resilience imperative.

Impacts of Artificial Intelligence

The incorporation of artificial intelligence represents one of the most profound changes in aviation since the introduction of fly-by-wire. AI systems already assist in decision-making in the cockpit (route optimization), predictive maintenance (with accuracy above 90% in several cases), real-time trajectory optimization, and air traffic management.

In 2025-2026, AI is partially integrated into intelligent cockpits and maintenance processes. The EASA eMCO-SiPO project (final report 2025) concluded that, with the current cockpit architecture, it was not possible to demonstrate an equivalent level of safety for extended minimum crew operations (eMCO) or single pilot operations (SiPO) in large-scale commercial air transport. The regulatory focus remains on hybrid human-AI solutions, integrated into the CBTA framework, with emphasis on digital literacy, bias mitigation, and algorithm transparency.

Projections indicate that, between 2030 and 2040, AI may reach higher levels of autonomy, allowing the pilot to act as a supervisor during extended cruise phases (particularly on cargo flights). Technical and human factors barriers persist, notably algorithmic opacity ("black box") and the potential increase in cognitive load. Future training should include advanced modules on machine learning principles, ethical limitations, and bias detection. Cognitive resilience — the ability to make decisions under uncertainty and ambiguity — will emerge as a central competency, incorporated into CBTA/EBT through hybrid human-AI scenarios. By 2040, pilots are expected to supervise autonomous systems in non-critical phases, preserving manual control during takeoff, landing, and emergency situations.

Operational complacency in the face of automation

Automation complacency remains one of the most challenging behavioral risks in human-automation interaction. Conceptualized as excessive trust in systems perceived as highly reliable, resulting in reduced active monitoring and cross-verification,[7] it manifests in aviation through undue dependence on the autopilot, weakening of cross-checks, and delays in manual intervention.

Quantitative research[6,8] demonstrates a positive correlation between trust in automation and complacency, especially in high-automation environments. In modern cockpits, this phenomenon aggravates the monitoring problem and compromises situational awareness during transitions to manual control. The distinction between calibrated trust (balance between efficiency and supervision) and excessive trust (source of risk) is fundamental. Mitigation strategies include regular manual flight practice, realistic failure scenarios, and the cultivation of a culture of independent questioning. On the 2040 horizon, with non-deterministic AI, the risk tends to intensify, demanding specific training in algorithmic transparency and resilience to surprise. Training must reinforce that automation is a support tool, never a substitute for human authority and judgment.

Fatigue and workload

Fatigue represents a persistent threat to operational safety, contributing to 15-20% of incidents and interacting negatively with automation by compromising the capacity for prolonged monitoring. On long-haul flights, severe fatigue is reported with high frequency, aggravated by night shifts, multiple sectors, circadian misalignment, and jet lag. Evidence indicates that fatigue significantly impairs decision-making, reaction time, and error recovery, with risk tripling in advanced phases of flight.

The interaction between fatigue and automation is particularly critical: during cruise, low stimulation can potentiate complacency; in emergencies, it delays detection and response. Although regulations such as EASA/FAA Part 117 establish prescriptive limits, Fatigue Risk Management Systems (FRMS) are essential for contextualized adaptation, using biometric data and voluntary reports. In 2024-2025, FRMS implementation in several airlines resulted in up to a 20% reduction in related incidents. AI emerges as a complementary tool for real-time physiological monitoring, although regulatory limits and the need for resilience education remain central.

By 2040, AI may assist in early detection of micro-sleeps, but interaction with autonomous systems tends to increase the cognitive load of supervision, potentiating fatigue. Training integrated into CBTA/EBT should incorporate fatigue education, mitigation strategies (such as strategic napping), and the promotion of a non-punitive reporting culture.

Conclusion and perspectives for 2040

Pilot training in commercial aviation has evolved from traditional task-based models to resilient, data-driven approaches (CBTA/EBT), adapting to increasing automation and the integration of artificial intelligence. Data from IATA (2025) and ICAO (2025) confirm the long-term trend of sustained reduction in accident rates, despite annual fluctuations, such as the punctual increase in fatality risk observed in 2025. This trajectory reinforces that continuous investments in human factors, competency-based training, and proactive risk management are fundamental elements for the preservation of safety.

The CBTA/EBT model, consolidated in 2025-2026 with majority adoption on a global scale (with the FAA conducting a comparative study in 2026)[9], has demonstrated effectiveness in mitigating risks associated with human factors through scenarios based on real data and assessment focused on observable competencies. This framework provides a robust foundation for deeper integration of AI technologies by 2040.

On the 2040 horizon, the pilot will tend to act as a manager and supervisor of highly automated and partially autonomous systems, with possible expansion of extended minimum crew operations (eMCO) during cruise phases, initially on cargo aircraft and later on passenger flights. Critical competencies will include effective intervention in the face of failures, calibrated questioning of algorithmic recommendations, and management of non-deterministic systems. Training should balance three fundamental pillars: technical mastery of the aircraft, effective supervision of automation and AI, and active understanding of intelligent systems, with emphasis on cognitive resilience, algorithmic transparency, complacency mitigation, and fatigue management.

The continued reduction of accidents will depend on investments in competency-based training, integrated FRMS, hybrid human-AI simulations, and greater algorithmic transparency. The future of safe aviation rests on close collaboration between regulators, manufacturers, operators, and academic institutions, ensuring that technological innovation is always harmonized with the preservation of human authority and judgment as irreplaceable elements of safety.

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None.

Conflicts of interest

Authors declare that there is no conflict of interest.

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