

# Training Challenges in Human – Artificial Intelligence (AI) Teaming in Aviation

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## ABSTRACT

Human–AI teaming is emerging as a defining paradigm in next-generation aviation, reshaping pilot roles, task distribution, and decision-making. As AI systems evolve into adaptive, semi-autonomous agents, aviation training faces challenges extending beyond technical skills to include trust calibration, cognitive adaptation, workload redistribution, and ethical responsibility. This paper examines key training challenges for effective human–AI collaboration. It first analyses the evolving operational landscape shaped by technologies such as adaptive automation and predictive analytics, which enhance performance but introduce risks including automation complacency, over-reliance, and skill degradation. Training must therefore enable pilots to critically monitor and, when necessary, override AI systems. The study further explores the pedagogical complexities of joint decision-making, emphasizing shared situational awareness, alignment of mental models, and the need to evaluate opaque AI outputs. Scenario-based training and explainable AI approaches are highlighted as essential tools. Finally, organisational and regulatory constraints are considered, including the lack of standardized competency frameworks. The paper argues for the expansion of CBTA/ EBT methodologies to incorporate AI-specific competencies and proposes a human-centric training model to ensure safe and resilient human–AI cooperation.

**Keywords:** Human–AI teaming, Aviation training, Evidence-based training, Safety-II, Artificial intelligence

## INTRODUCTION

Accident investigation has always been a challenge in disciplined research. Aviation has long been characterised by a delicate balance between human expertise and technological support. From early mechanical automation to contemporary flight management systems, each technological transition has required corresponding adaptations in training philosophy and practice. The current wave of artificial intelligence represents a qualitatively different shift. Artificial intelligence (AI)-enabled systems are no longer limited to executing predefined logic but increasingly exhibit adaptive, data-driven behaviour, learning from operational environments and influencing decision-making in real time. This transition challenges the traditional conception of

automation as a predictable tool and reframes it as an active participant in operational decision processes.

Within this context, human–AI teaming emerges not as a technological option but as an operational necessity. Pilots are expected to collaborate with systems that generate probabilistic recommendations, anticipate future states, and, in some cases, initiate actions autonomously. While these capabilities promise safety and efficiency gains, they also introduce new forms of vulnerability. Automation complacency, erosion of manual flying skills, inappropriate trust calibration, and ambiguity in responsibility allocation have already been observed in highly automated environments. Training systems, largely designed around deterministic automation and rule-based logic, are increasingly misaligned with the realities of AI-mediated operations.

This paper addresses these challenges through a human-centric lens. Rather than asking how pilots can adapt to AI, it asks how training systems can be redesigned so that AI remains compatible with human cognitive strengths, limitations, and ethical responsibilities. The analysis is grounded in contemporary regulatory and conceptual developments, including the European Union Aviation Safety Agency (EASA) Artificial Intelligence Roadmap 2.0, The International Civil Aviation Organization (ICAO)'s competency-based training philosophy, and emerging Safety-II perspectives that treat human variability as a source of resilience rather than error.

## **CONCEPTUAL FOUNDATIONS OF HUMAN–AI TEAMING**

Human–AI teaming in aviation represents a paradigmatic shift from tool-based automation toward socio-technical collaboration. Earlier generations of automation were designed around stability, predictability, and procedural containment. Pilots could reasonably anticipate system responses, rehearse failure modes, and anchor their situational awareness in deterministic logic. Artificial intelligence disrupts this equilibrium. Learning systems adapt to data, modify internal representations over time, and generate outputs that are probabilistic rather than rule-bound. As a result, pilots no longer interact with automation as a passive executor of intent, but as an active cognitive agent shaping perception, prioritisation, and decision framing.

From a human factors perspective, this transition has profound implications for cognition, authority, and responsibility. Teaming implies reciprocal influence. Humans adapt their strategies based on system behaviour, while AI systems infer human intent and operational context from data streams. This co-adaptation challenges classical models of situational awareness, which assumed a largely static relationship between operator and system. Instead, shared situational awareness must now be dynamically negotiated between human and machine, often under time pressure and uncertainty.

Trust calibration becomes a central construct in this environment. Trust is neither blind reliance nor sceptical rejection; it is a calibrated relationship grounded in understanding system capabilities, limitations, and uncertainty boundaries. Empirical studies in highly automated domains consistently demonstrate that miscalibrated trust leads either to automation complacency

or to under-utilisation of safety-enhancing functions. AI systems, by virtue of their opacity and adaptive behaviour, amplify this risk. Training systems must therefore move beyond teaching what the system does toward fostering understanding of why it behaves as it does, when its recommendations are reliable, and how to recognise degradation or bias.

The EASA Artificial Intelligence Roadmap 2.0 explicitly frames trustworthiness as a socio-technical property rather than a purely technical attribute. Transparency, human oversight, robustness, and ethical governance are presented as interdependent dimensions. Each dimension carries training implications. Transparency requires that pilots understand not only outputs but also confidence levels and contextual dependencies. Human oversight demands sustained monitoring skills and the confidence to intervene. Robustness requires exposure to degraded and unexpected modes during training. Ethical governance necessitates explicit engagement with responsibility, accountability, and moral agency in AI-supported decisions.

Human–AI teaming must therefore be understood as a competence-intensive activity. It draws on metacognitive skills, critical thinking, and adaptive expertise—capabilities traditionally associated with experienced aviators but insufficiently codified in training syllabi. These human capabilities are not residual skills to be preserved incidentally, but core competencies to be deliberately cultivated.

## **METHODOLOGY**

The study adopts a qualitative, interpretivist methodology aligned with the applied nature of aviation training research. Saunders’ research onion provides the overarching structure, guiding philosophical stance, methodological choice, and data interpretation. An interpretivist philosophy is adopted to capture the lived experience of pilots, instructors, and training designers interacting with AI-enabled systems. The research approach is abductive, integrating theory and practice iteratively to refine understanding of training challenges.

At the methodological level, the ICAO ADDIE instructional design framework—Analysis, Design, Development, Implementation, and Evaluation (ADDIE)—is employed as both an analytical lens and a structuring device for proposed solutions. In the analysis phase, current training practices are examined against emerging AI capabilities and regulatory expectations. The design and development phases focus on identifying competencies, learning objectives, and pedagogical strategies suitable for human–AI teaming. Implementation considerations address organisational readiness, instructor qualification, and integration within Competency-Based Training and Assessment (CBTA)/Evidence-Based Training (EBT) frameworks. Finally, evaluation emphasises continuous feedback, performance data, and Safety-II learning mechanisms.

This dual-framework approach ensures methodological rigour while maintaining operational relevance (Table 1). It allows training challenges to be examined not as isolated deficiencies but as systemic misalignments between technology, people, and organisations.

**Table 1:** Research methodology overview - alignment of addie phases with human–AI teaming competencies.

ADDIE Phase	Focus Area	Human–AI Training Outcome
Analysis	AI operational impact	Identification of cognitive and ethical demands
Design	Competency definition	Observable human–AI interaction behaviours
Development	Scenario construction	Exposure to uncertainty, drift, and conflict
Implementation	Instructor readiness	Consistent, human-centric delivery
Evaluation	Safety-II feedback	Continuous learning and adaptation

## FINDINGS

Key challenges include cognitive adaptation to opaque systems, workload redistribution, trust miscalibration, and ethical responsibility. These challenges demand training systems that prioritise sensemaking, adaptability, and professional judgment over procedural compliance alone are presented in Table 2.

**Table 2:** Training challenges associated with AI-enabled aviation operations.

Domain	Challenge	Training Implication
Cognition	Probabilistic and opaque system behaviour	Sensemaking and uncertainty management skills
Skills	Workload redistribution and automation surprise	Deliberate skill preservation and recovery training
Trust	Over-reliance or under-utilisation of AI	Trust calibration through scenario-based exposure
Ethics	Ambiguity of responsibility and moral agency	Explicit ethical reasoning and Just Culture integration

Within the context of human–AI teaming, Functional Analysis and Risk Integration (FAIR) 3 offers a critical lens for understanding how risk emerges not from isolated technical failures but from dynamic interactions among human cognition, intelligent systems, and organisational constraints. FAIR 3 extends traditional risk models by emphasising variability, coupling, and context, making it particularly relevant for AI-enabled operations characterised by probabilistic outputs and adaptive behaviour. In training environments, FAIR 3 supports a shift away from outcome-based risk assessment toward an examination of how decisions are shaped under uncertainty, time pressure, and competing cues. When applied to human–AI collaboration, FAIR 3 encourages pilots and instructors to explore how algorithmic recommendations, human judgement, cultural influences, and organisational norms interact to produce both successful and degraded performance. Embedding FAIR 3 principles within CBTA and EBT frameworks strengthens Safety-II learning by legitimising discussion of near-misses, weak signals, and successful recoveries, rather than focusing exclusively on deviations or errors. In this sense, FAIR 3 functions as a *cognitive bridge* between advanced automation and human adaptability, enabling training

systems to surface latent risk pathways and support resilient performance in complex, AI-mediated aviation environments.

➤ **Cognitive Adaptation and Mental Models**

One of the most significant challenges lies in supporting pilots' cognitive adaptation to AI systems whose internal logic may be non-transparent. Traditional automation training emphasised mode awareness and procedural compliance. AI systems require an additional layer of cognitive engagement: understanding confidence levels, data provenance, and contextual validity of recommendations. Without this understanding, pilots may either defer uncritically to AI outputs or dismiss them altogether.

➤ **Workload Redistribution and Skill Preservation**

AI promises workload reduction, yet empirical evidence suggests that automation often redistributes rather than eliminates workload. Monitoring adaptive systems, managing exceptions, and intervening during system uncertainty can increase cognitive load, particularly during non-normal situations. Training must therefore address not only routine operations but also degraded modes, ensuring that manual flying skills and problem-solving capabilities are preserved.

➤ **Trust, Ethics, and Responsibility**

Human–AI teaming raises profound ethical questions regarding accountability and moral agency. While AI may generate recommendations, responsibility for outcomes remains with human operators and organisations. Training must explicitly address this asymmetry, reinforcing ethical reasoning, Just Culture principles, and clear understanding of accountability boundaries. Without such grounding, pilots may experience moral disengagement or undue stress when interacting with autonomous systems.

➤ **Pedagogical Implications and Training Design**

Scenario-based training, instructor upskilling, and integration of explainable AI concepts are essential pedagogical responses. CBTA and EBT provide a robust foundation but require targeted extension to accommodate human–AI teaming competencies.

➤ **Organisational and Regulatory Considerations**

Training does not occur in isolation. Organisational culture, regulatory clarity, and standardisation significantly influence training effectiveness. The absence of harmonised human–AI competency frameworks across regulators complicates curriculum development and assessment. EASA's roadmap and ICAO's performance-based philosophy offer a pathway toward convergence but require sustained collaboration among regulators, operators, and training organisations.

Safety-II and FAIR 3 perspectives further underscore the importance of learning from normal operations and weak signals. AI systems can support this learning, but only if organisations cultivate a Just Culture that encourages reporting, reflection, and continuous improvement.

## **DISCUSSION**

The findings underscore the need for a systemic rethinking of aviation training. Human–AI teaming cannot be addressed through incremental updates; it requires a transformation of instructional design, assessment philosophy, and organisational learning mechanisms.

The analysis presented in this paper demonstrates that human–AI teaming is not a marginal extension of existing automation practices, but a fundamental reconfiguration of how work, authority, and responsibility are distributed in the cockpit and across the wider aviation system. Training systems that were designed around predictable automation and linear cause–effect relationships are increasingly misaligned with AI-enabled operations characterised by probabilistic reasoning, adaptive behaviour, and contextual sensitivity.

Confusion remains one of the most under-appreciated yet safety-critical challenges in AI-enabled flight operations. Traditionally, confusion in automated cockpits has been framed as mode confusion, arising from pilots misunderstanding the current state or logic of deterministic automation. In human–AI teaming environments, however, confusion assumes more complex and subtle forms. AI systems may generate recommendations that are contextually valid but cognitively opaque, probabilistic rather than deterministic, or temporally misaligned with pilots' expectations. As a result, pilots may experience uncertainty not only about what the system is doing, but why it is behaving in a particular manner and whether its reasoning remains aligned with operational intent.

In high-workload or time-constrained situations, such ambiguity can erode situational awareness and impair decision-making, especially when multiple sources of information compete for attention. Unlike classical automation surprises, which are often discrete and identifiable, AI-related confusion may persist unnoticed until operational margins are significantly reduced.

From a training perspective, confusion cannot be mitigated solely through increased system knowledge or procedural reinforcement. Human–AI confusion is fundamentally a sensemaking problem, rooted in mismatched mental models, incomplete transparency, and uncertainty about system confidence and limitations. Training programmes must therefore move beyond teaching nominal system behaviour and explicitly address how confusion arises, how it can be detected early, and how it should be managed operationally. This includes developing pilots' ability to verbalise uncertainty, articulate discrepancies between expectation and system output, and employ structured strategies for validating or challenging AI recommendations. Within CBTA and EBT frameworks, confusion should be treated as an observable and assessable behavioural condition rather than an individual cognitive failure. Effective human–AI teaming is demonstrated when pilots recognise emerging ambiguity, communicate it clearly, manage workload accordingly,

and take timely action to restore shared situational awareness. Scenario-based training that deliberately introduces ambiguous AI behaviour—without clear right or wrong answers—supports the development of these competencies. Debriefings grounded in Safety-II principles further enable crews to reflect on how confusion was managed successfully, reinforcing adaptive strategies rather than focusing exclusively on error avoidance.

FAIR 3 provides an additional lens for understanding confusion as an emergent risk condition rather than a discrete causal factor. From this perspective, confusion arises through the interaction of system design, human cognition, organisational expectations, and operational context. Training that incorporates FAIR 3 thinking encourages pilots and instructors to examine how confusion develops, how it propagates through the system, and how it can be contained before it escalates into unsafe outcomes. Addressing confusion explicitly within human–AI training is therefore not merely a matter of improving system familiarity, but of strengthening resilience, adaptive expertise, and ethical responsibility in increasingly complex aviation environments.

From a training perspective, this misalignment manifests as cognitive brittleness. Pilots may be procedurally compliant yet ill-prepared to interrogate AI outputs, recognise system drift, or resolve conflicts between human intuition and algorithmic recommendations. The findings therefore reinforce the need to reconceptualise competence as adaptive, reflective, and ethically grounded. These attributes cannot be assumed to emerge organically from experience; they must be deliberately cultivated through training design.

For Approved Training Organisations, the implications are substantial. Curriculum design must move beyond teaching system functionality toward developing sensemaking, uncertainty management, and judgment under ambiguity. Instructor roles must expand to include facilitation of reflective learning around AI behaviour, limitations, and ethical tensions. Assessment systems must be capable of capturing not only task success, but the quality of human–AI interaction, including appropriate challenge, monitoring, and intervention.

For operators, the introduction of AI intensifies the importance of organisational culture. Just Culture principles become more fragile in environments where algorithmic recommendations may be perceived as authoritative or blame-shifting. Training must therefore be embedded within broader organisational commitments to learning, transparency, and psychological safety.

For regulators, the findings highlight the urgency of harmonising human–AI competency frameworks and clarifying accountability boundaries. While EASA's Artificial Intelligence Roadmap 2.0 provides strategic direction, its effectiveness depends on translation into concrete training and assessment requirements aligned with ICAO's performance-based philosophy.

## **CONCLUSION**

The emergence of artificial intelligence as an operational teammate represents a structural shift in aviation operations and training rather than

an incremental extension of established automation paradigms. Human–AI teaming introduces new forms of cognitive demand, ethical responsibility, and organisational complexity that cannot be adequately addressed through traditional, procedure-centred training models. This paper has demonstrated that effective preparation for AI-enabled operations requires a reorientation of training systems toward adaptive expertise, trust calibration, sensemaking under uncertainty, and culturally informed decision-making. As AI systems increasingly shape perception, prioritisation, and risk interpretation, pilots’ ability to engage critically with algorithmic outputs is influenced not only by technical competence, but also by cultural norms related to authority, communication, and uncertainty tolerance. Ignoring these cultural dimensions risks misaligned trust, degraded teamwork, and fragile human–AI interaction in multinational operational environments.

To respond to these challenges, training for human–AI teaming must remain fundamentally human-centric, embedding AI-related competencies within competency-based training and assessment and evidence-based training frameworks. Integrating the ICAO’s ADDIE instructional model with Safety-II, FAIR 3, Cultural Intelligence, and Just Culture principles enables training organisations to cultivate resilience, ethical accountability, and sustained performance across diverse cultural and operational contexts. Cultural Intelligence functions as a resilience-enabling capability, ensuring that human variability becomes a source of adaptive strength rather than misinterpretation when interacting with intelligent systems. Rather than positioning artificial intelligence as a substitute for human judgement, future training systems must ensure that AI remains a cognitively and culturally compatible partner that enhances, rather than erodes, human adaptability. In doing so, aviation can leverage the benefits of artificial intelligence while preserving the human and cultural capacities that remain central to safety in complex, globally distributed operations.

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