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Why we need more showers in the aircraft: A neurocognitive perspective on the future pilot

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ABSTRACT: High levels of complexity in modern commercial aircraft and flight operations feature new accident types featuring a brittle flight crew response to increasingly frequent ambiguous and opaque non-normal situations. Previous work from the author proposes the Airmanship 2.0 concept to mitigate this brittleness by harmonizing the existing compliance-centred safety paradigm with an adaptive, sensemaking function in the flight deck. This article explores the neurocognitive sensemaking mechanisms that may enable this compound role, including related training considerations. A case study in mindfulness training is discussed as an initial practical exploration into such neurocognitive training of pilots. There are tentative indications of a positive impact of mindfulness on flight crew response to ambiguous situations, alongside key reflections on aviation cultural biases and (lack of) readiness for such advanced training.

KEYWORDS: Neurocognition, aviation, sensemaking, mindfulness, safety, CBTA

1. Introduction

The aviation industry's safety performance is very high. However, in the past two decades it has been struggling to continue reducing the accident rate (Airbus, 2025). Both accident investigations and safety research are identifying a new accident modality related to undesired interactions between increasingly complex aircraft systems and a strong emphasis on compliance (Mosier et al. 1998; Manzey et al., 2012; IATA, 2014; Man4Gen Consortium, 2015; Field et al., 2018; Woltjer et al., 2015; Banks et al., 2020; Landman et al., 2020; Hancock et al, 2022; Sarter, 2024; Mohrmann, 2026). Previous work by the author explored the nature of these accidents and identified key differences between crews that effectively navigate such complexity and crews that struggle to maintain safe flight operations in this context. Differences are mainly found in crews' abilities to make sense of an ambiguous situation and adapt beyond a purely procedural response.

Such recovery behaviors contrast with the current problem-solving behavioral standards for flight crew which are centered on monitoring and procedural compliance. The Airmanship 2.0 concept (Mohrmann & Stoop, 2019; Mohrmann, 2026) addresses this bifurcation through a compound pilot role, but in turn elicits a deeper question about the actual neurocognitive basis to interweave both compliant and adaptive behaviors. In other words, how may the concept of Airmanship 2.0 actually manifest in the cognition, neurology, cognition and biology of the human pilot?

This article unpacks the neurocognitive processes related to sensemaking of ambiguous situations, considerations in training and developing such processes and presents a practical case study in neurocognitive training of pilots for ambiguous and complex flight operations. Section 2 revisits the sensemaking challenges and Airmanship 2.0 concept as a point of departure, Section 3 explores the underlying neurocognitive mechanisms of sensemaking and Section 4 describes how these may be trained and applied in the context of flight operations. Section 5 presents a case study exploring such neurocognitive training in pilots, followed by a discussion of research, design and operational considerations associated with the proposed pilot control paradigm.

2. Safety in complexity

This section revisits the transitional challenge related to the pilot role and the proposal of a sustainable and harmonized *sensemaking function* through the Airmanship 2.0 concept. The reader is referred to Mohrmann (2026) for a more succinct examination of the theoretical and casuistic foundation of the Airmanship 2.0 concept.

2.1. A bifurcated pilot role

The very first pilots in the early days of initial fixed wing flight were avid cyclists: their functional role was to power the aircraft and manage basic lateral and vertical flight controls (Chant, 2002). In over a century since, the pilot role has evolved considerably beyond cycling, with the introduction of checklists, procedures, multi-crew operations and automation: all to accommodate the ever-increasing performance and efficiency requirements of a growing and developing industry. However, these developments also increased the complexity of systems and operations that pilots are managing to such an extent that pilots are (increasingly) detached from a deeper familiarity with and knowledge of aircraft systems (Woods, 2004; Langewiesche, 2009; Man4Gen Consortium, 2012; Saurin & Carim, 2012; IATA, 2014; Man4Gen Consortium, 2015; Stoop & Van Kleef, 2015; Woltjer et al., 2015; Prinzel et al., 2024). This introduced new human performance issues such as automation bias, monitoring errors and knowledge degradation (Weiner & Curry, 1980; Bainbridge, 1983; Sarter & Woods, 1994; Parasuraman & Riley, 1997; Mosier et al., 1998; Manzey et al., 2012; Mohrmann et al., 2015; Strauch, 2017; Kharoufah et al., 2018; Proctor & Van Zandt, 2018; Kelly & Efthymiou, 2019; Gago et al., 2025). To mitigate such "pilot errors", the industry furthered the shifting of tasks from pilots to automation as well as reinforce crew compliance to procedures, driving for safety through reproducibility.

While such reproducibility achieves significant safety performance, this safety paradigm is seemingly at its limits. In light of this, flight safety research (IATA, 2014; Man4Gen Consortium, 2015; Woltjer et al., 2015; Field et al., 2018; Banks et al., 2020; Landman et al., 2020; Hancock et al., 2022; Sarter, 2024; Mohrmann & Field, 2026) in the past two decades has been pointing to a relative increase in (crew-experienced) ambiguity and opacity related to the complexity and reliability of modern (e.g., fourth generation) aircraft, coupled with compliance-conditioned flight crews struggling to make sense of and resolve such situations which are unfamiliar and non-deterministic. The growing complexity of aircraft systems has, ironically, resulted in flight crew not proficient in managing that complexity. The desired resilient response to complex, ambiguous and opaque situations enables creative, dynamic problem-solving which can be described as the process of *sensemaking* to formulate effective responses to an opaque situation (Hollnagel & Woods, 2005; Rankin et al., 2016; Mohrmann et al., 2015; Mohrmann et al., 2017; Sarter, 2024).

This introduces a bifurcation in the pilot role: on the one hand requiring a high level of procedural compliance and basic task proficiency (e.g., lowering the gear), while on the other hand requiring pilots to demonstrate acute, dynamic sensemaking and problem solving in rare (but often critical) opaque and ambiguous situations lacking prescriptive solutions. This is often sardonically referred to by pilots as *"…endless hours of sheer boredom, punctuated by moments of stark terror."* (Diehl, 2013). The near opposition of these control paradigms features contra-reinforcement (e.g., heavy use of compliance decays adaptability), mutable behavioral standards and unidirectional optimization of Joint Cognitive System (JCS) designs (Mohrmann, 2026). As such, these phenomena void the (implicit) assumption that pilots are readily proficient in both control paradigms and call for explicit harmonization of both paradigms into a single, non-bifurcated pilot role. Mohrmann & Stoop (2019) proposes the Airmanship 2.0 concept to achieve this.

2.2. The Airmanship 2.0 concept

The Airmanship 2.0 concept proposes an adaptation of Tony Kern's airmanship model (Kern, 2010). The apex of Kern's model is proper awareness and judgement, supported by five pillars of knowledge, which are in turn supported by a foundation of proficiency, skill and discipline. As such, this model aptly describes the pilot role for transparent operations, where an upkeep of proficiency and knowledge supports an effective recognize-and-act way of working, such as Klein's (1996) Recognition-Primed Decision-making (RPD) model. The Airmanship 2.0 concept adapts this model by systematically *nesting* compliant behaviour *within* a sensemaking approach. This follows a *fail-safe* approach to the blend of transparent and opaque situations crews may encounter. In other words:

> *It is safer to assume opaque operations and, upon realizing that a situation is transparent, transition to a prescribed action, rather than assuming that an opaque situation is simpler than it is.*

The Airmanship 2.0 concept leverages innate human competence in sensemaking to learn and adapt in the face of opacity and ambiguity. Critically, the proposed concept retains existing compliance safety performance by nesting existing workload- and error-reducing behaviours (e.g. procedures) within this process of sensemaking. By defining a unified yet compound role, this concept prevents pilot skill decay by design in both compliance and adaptivity, while avoiding straining pilots in role-bifurcation. The proposed nesting is achieved through three adaptions to Kern's model, as illustrated in Figure 1.

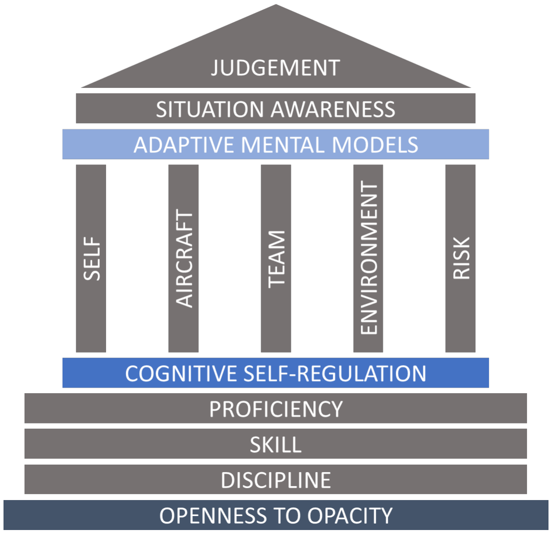

Figure 1. The Airmanship 2.0 concept (Mohrmann, 2026)

The first is establishing a foundation of belief and *acknowledgement* of non-deterministic realities to widen a pilot's safety aperture and support proactive, continuous Threat and Error Management (TEM) (Dekker, 2014). The second adaption is the pilot's *cognitive self-regulation* to maximize cognitive resources required for sensemaking and (the pillars of) knowledge during opaque situations. This adaption also critically mitigates the increased propensity for startle and surprise that comes with highly reliable and complex systems (Martin & Sloman, 2013; Rivera et al., 2014; Field et al., 2018; Landman et al., 2020; Gardini et al., 2022; Vlaskamp et al., 2025).

The third adaption is maintaining *adaptivity in mental models* to make sense of non-deterministic situations. This does not imply that pilots should doubt every mental model they have learned, but that they recognize that these models are limited to underlying assumptions, and that reality may prove to work differently. This attitude mitigates confirmation bias and could be operationalized through practical sensemaking strategies as proposed in the Man4Gen project (Field et al., 2017; Mohrmann et al., 2017). Readers are referred to Mohrmann (2026) for further details and reflections of the Airmanship 2.0 concept.

These three proposed adaptions to the airmanship concept are believed to facilitate a sensemaking response that is symbiotic to the deterministic response (i.e. compliance-based response). While this outlines desired flight crew response at a conceptual level, it fails to articulate how this manifests cognitively, and – critically – how this in turn can be conditioned and trained. This requires a deeper appreciation of the human neurocognition of sensemaking (particularly under ambiguous circumstances), which is the subject of Section 3.

3. The Neurocognition of sensemaking

The neurocognition around learning sand specifically sensemaking is complex to say the least, and a full and comprehensive review of the science of cognition is beyond the scope of this work. This section will explore the main neurocognitive processes around sensemaking, with a particular focus on the context of ambiguous and complex situations. Section 3.2 will reflect how these processes facilitate the compound nesting proposed in the Airmanship 2.0 concept.

3.1. Different neurocognitive pathways for sensemaking

At a basic level, our brain makes sense of the world through a perpetual cycle of processing inputs that modify an existing understanding or model of the world, which in turn directs our decisions and actions, a basic process described by Neisser (1976). However, at a neurological level, this basic concept of cyclic sensemaking can run through very different neural networks and brain cortices and have their independent merits and drawbacks. As a point of departure, it is worth appreciating three long-held and widely studied theoretical constructs of our cognition and sensemaking mechanisms:

1. Skill-rule-knowledge based behavior (SRK) (Rasmussen, 1983)
2. Recognition-primed decision making (RPD) (Klein, 1996)
3. Dual process theory (DPT) (Kahneman, 1982)

Table 1 provides a high-level summary of these constructs. All three constructs have in common a basic appraisal of both autonomous, intuitive sensemaking as well as conscious, conceptual, analytical sensemaking, a bifurcation aptly described by the French philosopher Blaise Pascal as “*esprit de finesse”* (intuitive mind) and “*esprit de geometrie”* (analytical mind) (Pascal, 1670/1995; Barrouillet, 2011). Furthermore, they all underscore the close coupling of sensemaking and decision making: our decisions are indeed based on our (possibly inaccurate) understanding of the situation. This is important as sometimes the decision-making context drives a particular sensemaking strategy (and vice versa), which will be discussed below.

Table 1. Summary of three legacy theoretical sensemaking constructs

Construct	Description
SRK Construct	Behavior occurs at three levels: *skills* (sensory-motor/reflex response), *rules* (pre-determined responses) and *knowledge* (analytical response).
RPD Construct	Understanding ("frame") of the situation is initially mapped heuristically to previous experiences. Mapping errors trigger an analytical/reframing response to create a new frame.
DPT Construct	The brain operates by default on a fast and frugal mode that uses heuristic thinking (System 1) but can also engage a cognitively more demanding analytical response (System 2) if System 1 delivers errors.

Behavioral and neurological research in the past decades provides a more succinct appreciation of our cognitive sensemaking and decision-making processes. Five key nuances to these three legacy models of cognition (relevant for the context of modern aviation) are articulated in the following subsections.

3.1.1. Nuance 1: Multi-faceting of "intuition"

The sensemaking that happens outside of our conscious experience seems to be more complex than simply a fast, frugal and primed response (DPT System 1) and has been connected to heuristic, associative, holistic, inferential, and affective dimensions (Hill, 1987; Stanovich & West, 2000; Volz et al., 2008, Stanovich, 2011; Dennin et al., 2022; Svenson et al., 2023). From a sensemaking perspective, research is identifying a range of responses ranging from a heuristic pattern-matching response to a holistic generative response (Glöckner & Witteman, 2010; Chassy & Gobet, 2011; Dreyfus, 2014; Pennycook, 2015). These responses also feature distinct neural processes, with recognition-based responses featuring more engagement of memory areas like the ventro-lateral Pre-Frontal Cortex (vlPFC), Orbito-Frontal Cortex (OFC) and a strong connection with the limbic system (discussed in nuance 3)

(Cohen et al., 2005; Poudel et al., 2020; Salehinejad et al., 2021; Colautti et al., 2022; Williams et al., 2025), while insight-related experiences feature different cortical activation around the ventro-medial PFC (vmPFC), parietal lobe and OFC (Volz et al., 2008; Aldous, 2007; Kounios & Beeman, 2009; Andersson et al., 2020). Furthermore, there is evidence for hemispherical differences where the brain's right hemisphere is activated more for remote associations and creativity, while the left hemisphere is more often activated for tighter associations and recognition (Jung-Beeman, 2005; Kounios & Beeman, 2009; McCrea, 2010; Hruska et al, 2015). Other neurocognitive research into the brain's Default Mode Network (DMN) has brought that system in connection with creative ability, coherence-evaluation and generative responses (Beaty et al., 2014; Kühn et al., 2014; Zedelius & Schooler, 2015; Luchini et al., 2025).

In summary, the alternative to conscious, rational sensemaking is not merely a heuristic fast lane, but a more complex interplay between sensorineural inputs, declarative memory (i.e., stored information), procedural memory (brain synaptic "habits")[1] and affect (i.e., emotional tags). Nuance 4 will explore the activation of both heuristic and holistic sensemaking responses.

3.1.2. Nuance 2: Interactivity of sensemaking modalities

All three SRK, RPD and DPT constructs describe distinct sensemaking modalities or systems. In extension of the heuristic and holistic responses described in Nuance 1, the brain also features a generally more familiar conscious, rational, analytical response (Rosenbloom et al., 2012; Hruska et al., 2016; Poudel et al., 2020; Hannah et al., 2022). This activates different brain areas including the dorso-lateral PFC (dlPFC) for working memory and executive function, dorsal Anterior Cingular Cortex for emotional regulation and insula for salience attention switching (Menon & Uddin, 2010; Collins & Koechlin, 2012; Kühn et al., 2014; Poudel et al., 2020; Salehinejad et al., 2021; Colautti et al., 2022; Williams et al., 2025).

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[1] This refers to neurological "procedural memory" i.e. neural structural modification (see Chassy & Gobet, 2011; Dreyfus, 2014; Conway-Smith & West, 2022). Not to be confused with aviation "procedural knowledge".

The existence of multiple systems has led to (at least) three explanations in how they interact: default-interventionist, parallel-competitive and fuzzy-trace.

The default-interventionist explanation (Evans & Stanovich, 2013) describes a default heuristic (fast and frugal) response to a situation, which can subsequently be intervened upon by an analytical, conscious response if the heuristic response doesn't manifest effectively. This also raises the question whether a meta-system is required to monitor both responses and trigger or inhibit intervention (Nadurak, 2023; Shaw & Nave, 2026). The parallel-competitive explanation (Martin & Sloman, 2013) explains that both intuitive and rational processes co-exist and that the brain chooses the most appropriate response from either approach. A third explanation is the fuzzy-trace theory (Barrouillet, 2011; Reyna, 2012; Blalock & Reyna, 2016) which describes making sense of a situation either through its verbatim "trace" (e.g., text, numbers, graphics) or by a situations bottom-line meaning known as a "gist" (e.g., gain/loss, confidence, sense of uncertainty). Studies show that gist appreciation is often preferred when making decisions, and in some cases may also be the preferred decision-making perspective when facing ambiguity or stochastic extremes (discussed in Nuance 4). Neurological research confirms multi-processing, but rather in a collaborative way rather than a competitive way, often described as a quasi-rational interaction between intuition and insight (Hodkinson et al., 2008; Zander et al., 2016; Calabretta et al., 2017; O'Doherty et al., 2017; de Neys & Pennycook, 2019).

These studies describe a process where intuitive sensemaking feeds rational insight with novel hypotheses, ideas and constructs (not all plausible, of course). In turn, rational sensemaking provides gaps, queries and problems for heuristic and holistic appraisal. Together, these processes become effective in coherence building (Öllinger & Von Müller, 2017; Akinci & Sadler-Smith, 2020; Van den Berg et al., 2020; Woiceshyn, 2022), which is also supported by brain hemisphere co-activation studies (McCrea, 2010; Hruska et al., 2016; Zamani, 2019; Anderson et al., 2020). In summary, effective and context-responsive sensemaking should appreciate the interaction and value of both conscious, deliberate processes as well as unconscious, tacit ones, without the illusion that one can consciously select between them.

3.1.3.Nuance 3: The role of emotions and affect

It is now recognized that both conscious and unconscious mental processes can be influenced by emotions originating from our limbic system (Hogarth, 2002; Dane & Pratt, 2007; Glöckner & Witteman, 2010; Chassy & Gobet, 2011; Salehinejad et al., 2021; Dennin et al., 2022), known as an *affective response* to stimuli. In the domain of executive functioning (EF) i.e. conscious, top-down, deliberate thinking, strong affective decision making is termed “hot EF”, which features more limbic engagement through the ventral PFCS and ACC, Posterior Cingular Cortex (PCC), amygdala and insula. In contrast, “cold EF” features less limbic activation and relies more on dorsal and lateral brain regions (Poudel et al., 2010; Salehinejad et al., 2021). Research into such EF shows a strong coupling of hot EF and cold EF with the nature of the situation featuring either risk or ambiguity (Krain et al., 2006; Poudel et al., 2020; Salehinejad, 2021; Colautti et al., 2022). The contexts of reward, value and punishment as well as decisions implying risk (e.g. outcome uncertainty) feature a strong activation of hot EF, such as monetary gains/losses or strong social implications. In contrast, cold EF presents when the situation features no emotional valence, or when experiencing ambiguous situations (e.g. when options are equivalent, discussed in Nuance 4). Affect has also been connected with intuitive appraisal of one’s own sensemaking through a metacognitive *feeling of rightness* (Thompson, 2009; McCrea, 2010; Thompson & Morsanyi, 2012), which in turn may also be connected with somatic markers (Ten Houten, 2016) and fluency of retrieval (Volz et al., 2010). How the brain integrates and weighs both internal (e.g. emotional) and external stimuli is still a very active field of research.

Two large meta-studies (Lerner et al., 2015; George & Dane, 2016), exploring 35 years or research in the function of emotions in our sensemaking and decision-making, highlight that emotions can introduce bias, but can also provide useful “metatags” to our stimuli. Critically, the ability to recognize emotions for the role they (can) play is critical. Some explorations into emotional regulation in the field of aviation have focused on recovering from startle and surprise events and strong amygdala responses to mitigate bias (Field et al., 2018; Landman et al., 2020; Duchevet et al., 2024; Vlaskamp et al., 2025). Research by Brand et al. (2007) indicates the amygdala and limbic responses may even improve decision making under uncertainty, yet this positive contribution of limbic tacit knowledge is still to be explored in the context of aviation sensemaking.

3.1.4. Nuance 4: The nature of the situation

The nature of the situation has a profound impact on the activation and effectiveness of various sensemaking mechanisms, both conscious and unconscious. One particular distinction is that between well-structured problems where rules and principles can be applied, and poorly structured problems where no rules or principles have been established and feature significant ambiguity. Through a cognitive lens, the nature of ambiguity can better be understood as *equivocality of options*: an "excess" of certainty, rather than a lack of it (Zeki, 2004; Carleton et al., 2007; Reed, 2015; Julmi, 2019; Stoycheva, 2025). Consider multiple options (e.g. diversion airfields) that have respective pro's and con's in multiple dimensions. Studies show that in such situations, a conceptual, analytical approach does not provide additional sensemaking contrast, and a holistic intuitive appraisal can lead to a better decision (Sadler-Smith & Shefy, 2004; Dane & Pratt, 2007; Dörfler & Ackermann, 2012; Julmi, 2019).

Nuance 3 already introduced another contextual sensitivity for risk and ambiguity in relation to affect. This is furthermore supported by hemispherical differences in the parietal cortex, where straightforward and well-structured problems featured conceptual, left brain activation of regions connected with numbers and comparisons, where ambiguous and less straightforward situations resulted in holistic, right brain activation of regions connected with spatial awareness, visualization and creativity (Krain et al., 2006; Aldous, 2007; Zedelius & Schooler, 2015; Fabio & Towey, 2018; Williams et al., 2025). A possible human factor key to effective ambiguity management is an individual's *tolerance for ambiguity*

(Carleton et al., 2007; Stoycheva, 2010; McLain et al., 2015; Stoycheva, 2025). Studies in medical (Iannello et al., 2017) and air defense personnel (Adams-White et al., 2017) highlighted the value of tolerance for ambiguity in contexts that featured regular ambiguity and may prove to be a valuable domain for selection and training of future aircrew.

3.1.5. Nuance 5: Differences between experts and novices

A final important nuance in sensemaking is appreciating the interaction between expertise and sensemaking. Studies in the domain of medical diagnostics and chess players show distinct differences between novices and experts (Hodgkinson et al., 2008; Epstein, 2010; Dreyfus, 2014; Klein, 2015) dealing with ambiguity[2]. A notable difference is novice recruitment of mainly top-down conceptual analytical regions and uncertainty estimations (left vlPFC), where experts rely more on holistic intuitive functions, spatial perception, pattern recognition and memory (right dlPFC, parietal cortex) (Hogarth, 2002; Hruska et al., 2016; Hannah et al., 2022; Williams et al., 2025). This is not unsurprising as domain novices do not feature the implicitly learned experiential basis and tacit relational knowledge (De Houwer, 2019) required for heuristic and holistic sensemaking and may therefore best approach problems in a deliberate fashion. There is even light evidence that effective ambiguity management is positively correlated with older age (Zamarian et al., 2008). As such, a differentiation between novice and expert sensemaking may implicate differences in their respective sensemaking contributions, and sensemaking training.

3.1.6. Overview of sensemaking archetypes

The five nuances showcase a much more dynamic and multi-factorial playing field that drives which cognitive processes are (or should be) engaged. While the research into these neurocognitive functions is still very much ongoing, a re-appraisal of these functions in the context of complex and

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[2] While the game of chess features characteristics of a well-structured problem with clear rules, it is considered an ill-structured problem due to the diversity of both player's options and behaviors, with the number of game possibilities (Shannon number) of around 10^{120} (Newell & Simon, 1972).

ambiguous flight operations provides a more actionable construct for the manifestation of Airmanship 2.0. Table 2 proposes three sensemaking neurocognitive archetypes and key factors that distinguish them.

Table 2. Overview of sensemaking neurological archetypes

Sensemaking neurocognitive archetype	**Conceptual sensemaking**	**Heuristic sensemaking**	**Holistic sensemaking**
Makes sense by	Cause-effect modelling (reconstructing) a complex situation or system	Identifying similarities to other (previous) experiences and situations (schemas)	Immediate appraisal of the situation gist through internal symbology
Mechanism	Conscious, rational (“cold” executive function)	Mostly unconscious, affective (“hot” executive function)	Unconscious, affective, direct stimuli valuation (a-rational function)
Useful for	Hypothesis testing, coordinating a model with other actors	High-risk situations (time pressure, stochastic uncertainty)	Highly ambiguous situations (equivocality of options)
Limitations	Time consuming; limited in resolving ambiguity	Oversimplification of schemas and affective bias risk	Some affective bias risk; expertise required (tacit knowledge)
Relative brain activation	dlPFC; dACC; insula	vlPFC; mPFC; OFC; vACC; PCC; amygdala; insula	dlPFC; vmPFC; ACC; OFC; amygdala; insula; basal ganglia
Developing this requires[3]	Stimuli sensitivity training (allo-centricity)	Emotional regulation training; explicit learning (training scenarios)	Emotional awareness training; implicit learning (tacit knowledge and symbology)

It must be re-emphasized that these are not distinct, selectable modalities of sensemaking, but rather serve to illustrate three zones across a *spectrum of sensemaking*, also highlighted by the close proximity and overlap of cortical region activation. However, this neurocognitive disambiguation of sensemaking mechanisms helps to identify their relative utility in navigating opaque situations. Three key points become clear in this regard:

1. *Conceptual* sensemaking has limitations the face of ambiguity,

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[3] Training of sensemaking archetypes is addressed in Section 4.

2. The possible value of *intuitive holistic* sensemaking in responding to ambiguity, and
3. The influence of *affect* on our intuitive responses.

3.2. Sensemaking neurocognition in the context of cockpit operations

The Airmanship 2.0 concept was incepted to enable effective flight crew responses to the full range of situations, both transparent and opaque, ambiguous and complex. Where procedural responses are effective for transparent situations (which are neither ambiguous nor complex), effectively navigating opaque situations may require a deeper appreciation of the above repertoire of sensemaking mechanisms relative to the nature of the opacity experienced. The relative virtues of conceptual, heuristic and intuitive sensemaking varies across two *dimensions of opacity*:

1. Ambiguity: Is the situation/problem well-defined or ill-defined;
2. Complexity: The number of variables and dimensions in the situation/problem;

Figure 2 below depicts which responses may be most appropriate based on the nature of the situation. This being a simplification, it should be regarded as a starting point to make sense of sensemaking. The responses will be briefly discussed with an example (from left to right):

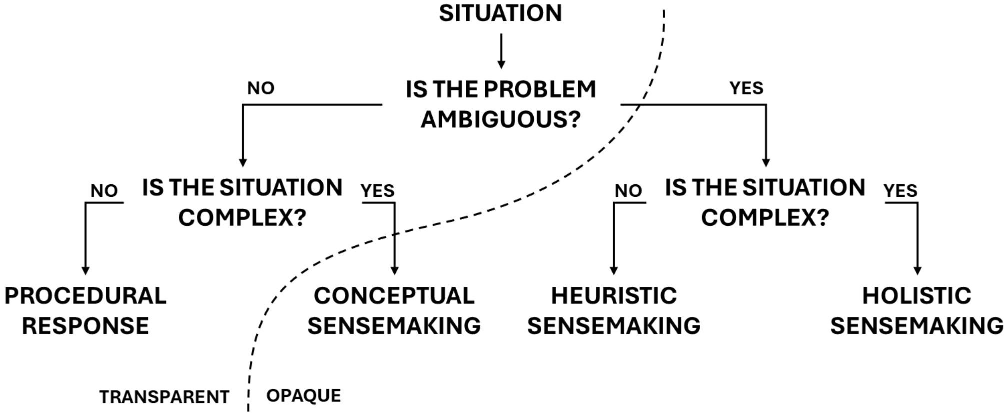

Figure 2. Possible classification of neurocognitive sensemaking according to dimensions of opacity

Situations that are not ambiguous and not complex are *transparent*, and as such do not feature any opacity that requires sensemaking. In such situations, the existing deterministic, procedural response is effective without requiring further sensemaking. For example, a single aircraft electrical generator failure where a reset, circumvention or auxiliary replacement procedure can be performed according to the aircraft and operator's standard (non-normal) operating procedures. A situation which is not ambiguous but *is* complex does qualify as opaque due to the existence of multiple concurrent developments (e.g., failures, trends) or contingencies that are not merged into a pre-determined response. For example, two concurrent generator failures where two or more unprioritized procedures may apply. In this case a *conceptual* sensemaking approach is applicable as the problem is well-defined and allows for rational cognitive modelling. While more rare than transparent situations, this response has already received significant guidance and training in past decades through mnemonic responses such as FORDEC, DESIDE and T-DODAR (Li et al., 2014; Banks et al., 2020).

Further to right in Figure 2, situations that *are* ambiguous provide a challenge where multiple explanations or alternatives are cognitively experienced as equivocal. This is not a problem of lack of information, but rather a problem of insufficient contrast (Zeki, 2004; Julmi, 2019). In ambiguous situations which are *not* complex, a heuristic response may already provide a sufficient appraisal of the situation. For example, a generator that drops 30% of output every 18 or so minutes, which could be (heuristically) rationalized as either a failed generator, a surging engine or another intermittent failure and their associated responses. For situations which are both ambiguous *and* complex, holistic appraisal is most appropriate. For example, an intermittently failing generator and an AC-bus failure may give a (gut) sense that the greater electrical system is not to be trusted (an example of a situation's bottom-line *gist*).

The appreciation of different modalities of opacity is important for future flight crew to identify the most effective sensemaking and decision-making approach. A fundamental *openness to opacity* as described in the Airmanship 2.0 concept may be established through the simple appreciation of the modalities presented in this article, without a strict "proceduralizing" of the tree presented in Figure 2. These sensemaking modalities can only truly be supportive to flight crews when they are recognized for their value in resolving ambiguous and/or complex situations.

All sensemaking modalities have interactions with the limbic system, which can be both a positive and negative force. Conceptual sensemaking (which is mainly a Pre-Frontal Cortex (PFC) activity) can suffer from a strong stress response where PFC activity is reduced. Recognition of this effect and recovery of PFC activity is essential for this sensemaking modality to function and has been a central objective for many startle and surprise recovery training programs. In contrast, heuristic sensemaking taps into "emotional tags" as part of the heuristic knowledge base. As such, regulation of the emotional state becomes important to ensure that a pilot benefits the most from his/her total cognitive capacity (including emotional memory), without becoming too biased by his/her current emotional state. Lastly, the intuitive, holistic sensemaking process also engages emotional memory, but does so in a subconscious, a-rational manner. Similar to heuristic decision making, current emotions may also impact what subconscious patterns and memories drive an underlying "gut feel", however this can be appreciated less as it does not preside in our conscious brain. For this reason, regulation (and awareness) of both acute and chronic emotional arousal may be essential to maintain the accuracy of all our sensemaking abilities and may be required as an integral trait of the future pilot as proposed in the Airmanship 2.0. concept.

The third important translation of these neurocognitive sensemaking modes to the flight deck underscores their very output: *a novel understanding of reality*. In transparent situations, established mental models guide both awareness and decision making. In opaque situations, these models do not map to the situation, and a revised understanding (e.g., more detailed, rescoped, adaptive) is the result of either analysis, heuristics or intuition. In flight operations, the explicit appreciation that *existing mental models may be limited* is essential to be able to appreciate the output of any sensemaking activity. These model adaptations do not have to be significant and may even be situational (e.g., only this route, aircraft, crew), but they must be admissible inputs to build situation awareness and base decisions on. Both the adaptivity of mental models and openness to opacity underscore the very real possibility of a non-deterministic situation (albeit rare) and would require a pilot's personal tolerance for ambiguity (Stoycheva, 2025). Such openness, tolerance, adaptivity and emotional regulation invites a reappraisal of flight crew training for these sensemaking modalities to function effectively, which is the subject of Section 4.

The consolidation of these sensemaking abilities through Airmanship 2.0 does not represent a radical departure from prescriptive, procedural operations but rather proposes an enhanced way of using existing procedural elements. A basic mantra would indeed be: "*the checklist is a tool, not a plan*". Most pilots will acknowledge that this mantra has been part of their training at some point, although pilots will vary widely in their dedication to living by it, depending on their background, experience, attitude, company standard operating procedures and cognitive abilities. It is an illusion that subsequent generations of pilots will be procedure-free and completely unconstrained in their strategies to manage complex and ambiguous aircraft systems and operations. Procedures offer key advantages (e.g., standardization, shared awareness, protection against slips and lapses) and will continue to play an invaluable role in reducing the mental workload associated by partitioning complex interactions of humans, systems and operations into manageable working instructions. However, they may greatly be improved upon if they can be framed and recognized for their sensemaking value, rather than only their executive contribution. The implication of this way of working is that the pilot no longer faces the existential "*do I comply or do I deviate*" role bifurcation. Instead, he/she may comply with procedures within a (meta-)process of learning about and resolving situations. An important implication of this is that “deviations” no longer exist as an error mode: procedures are no longer the operational gold standard, they are (merely) tools for the pilot to use. This shift in standards will briefly be discussed in Section 6.

Taken at face value, the Airmanship 2.0 nested way of working would seem to suggest potential increase in mental workload. Rather, it underscores the value of open-awareness and intuitive salience sensitivity (coupled with a fail-safe *mindset*) as low workload “canaries in the coalmine” (Menon & Uddin, 2010). Mental workload will only increase if indeed the situation is requiring an activation of conceptual sensemaking which requires considerably more working memory (Andersson et al., 2020; Salehinejad et al., 2021).

4. Training sensemaking

The deeper apprehension of sensemaking neurocognition invites a re-appraisal of how pilots are trained to develop competence across all three sensemaking archetypes. This section will differentiate between novice and expert pilots in line with Nuance 5 and as well as argue the necessity of novice-expert teaming for diversity of sensemaking mechanisms and – critically - ensuring continuity in workforce expertise.

4.1. Training novice pilots

Novice pilots may be the subject of two evolutions in training: the first is expanding the *general professional foundation* of a pilot with a tolerance of ambiguity and emotional self-regulation which is carried forward through their career. The second is novice-specific neuro-cognitive training to enhance conceptual sensemaking by increasing *external* stimuli awareness and reducing *internal* limbic and self-referential inputs (which can be considered “noisy signals” when such internal inputs aren’t sourced from a broad foundation of experience, expertise and knowledge).

As novices lack the tacit knowledge and experience to solicit expert intuition, they may best engage a conceptual, top-down rational approach to sensemaking. At the neurocognitive level, four distinct training objectives can be identified for novice pilots:

1. A basic tolerance for ambiguity (openness to opacity) to appreciate the value of sensemaking;
2. Down-regulation of emotions to reduce self-referential “noise” and maintain Pre-Frontal Cortex (PFC) working memory;
3. Increased attentional control for sensitivity to external stimuli, improving the quality of inputs to the sensemaking process;
4. Fluency in conceptual sensemaking techniques contextualized for flight operations;

An important second-order effect of the above requirements may be a greater resolution and quality of the developed tacit knowledge and internal schemas (Talbot, 2004, Klein, 2015) that result from a richer experience of stimuli – i.e., a sharper intuition. This is essential to ensure availability of expert intuition in the future.

A promising avenue for novice neurocognitive training is mindfulness training. Mindfulness proficiency potentially addresses all four training objectives. Developing mindfulness through *focused-attention meditation* practice has been shown to reduce self-referential thinking (training objective 2) by reducing Default Mode Network (DMN) activity (Farb et al., 2007; Brewer et al., 2011; Marchand, 2014; Garrison et al., 2015; Tang et al., 2015; Li et al., 2020) and improve allo-centric attentional control to external stimuli (training objective 3) (Pagnoni et al., 2008; Hölzel et al., 2011; Garrison et al., 2015; Oken, 2016; Bremer et al., 2022). The same attentional control mechanism also improves emotional awareness (training objective 2) and in turn emotional self-regulation (Hölzel et al., 2011; Marchand, 2014; Tang et al., 2015; Mansouri et al., 2025). Mindfulness has also been connected with a faster post-stress deactivation of the amygdala (such as after a startling or surprising event) (Brewer et al., 2011; Hölzel et al., 2011; Meland et al. 2015, Alaydi et al., 2025). From a sensemaking perspective, this improves accessibility to cold executive functioning (EF) and attenuates hot EF and intuitive functions (training objective 4). There is even evidence that mindfulness improves creative problem solving through *analysis* (Zedelius & Schooler, 2015; Berkovich-Ohana et al., 2017; Byrne & Thatchenkery, 2019). Furthermore, mindfulness training may also develop a novice's openness to opacity (training objective 1) by reducing a need for control (egocentric response). Evidence of this is found in the context of Zen training where training in ambiguity acceptance is a central tenant through concepts such as *wu-wei* ("not-doing") and koan training (Brezina, 2011; Low & Purser, 2012; Austin, 2013; Li, 2014).

Beyond the cognitive foundation provided by mindfulness, effective conceptual sensemaking requires integration into normal operations to avoid its atrophy (Mohrmann, 2026). This could possibly be achieved by adapting existing aviation-relevant problem-solving mnemonics such as FORDEC, DESIDE and T-DODAR as vehicles to operationalize conceptual sensemaking on the flight deck (training objective 4). As the high reliability and standardization of modern flight operations provides infrequent opportunities to develop sensemaking in operations, training programs for novices must feature a large amount of context-rich and (progressively) unguided training to practice and gain confidence in their sensemaking abilities, be tolerant of ambiguity and grow their repertoire of solutions and internal schemas. An example of such exploratory, unguided training was recently explored by Van Leeuwen et al. (2024). This type of simulated training can be supported by on-the-job development of expertise through *deliberate performance* (Fadde & Klein, 2010). Such training captures job experience explicitly as expertise-building opportunities to build better mental models, rather than only relying on implicit learning. This concept strongly mirrors the Zen concept of *work-practice.* In the domain of Competency Based Training & Assessment (CBTA), this is often referred to as developing *self-reflecting practitioners.*

4.2. Training expert pilots

Expert sensemaking training proposes building on the above foundation of novices by assuming a existing tolerance for opacity, proficiency in emotional regulation, conceptual sensemaking and (growing) tacit knowledge and experience base. Training experts should focus on developing proficiency in heuristic and holistic sensemaking to manage particularly ambiguous situations, addressing the following training objectives:

1. Increase the expert's aperture to intuitive responses and implicit knowledge;
2. Improve creativity and remote association of concepts;
3. Fluency in heuristic and holistic sensemaking techniques contextualized for flight operations;

Training familiarity with intuitive responses requires tuning into implicit, internal knowledge including affective, somatic and a-rational experiences (i.e., insight, or "aha-erlebnis"). This is a departure from the novice pathway which was focused at quieting such bottom-up internal signals in favor of external stimuli and top-down rationalization. Neurologically, this implies a more active Default Mode Network (DMN) for improved creativity in response to ambiguity, by means of more active associative thinking (Volz et al., 2014; Berkowich-Ohana et al., 2017; Fabio, 2018; Luchini, 2025). Remmers et al. (2015) also hypothesize that a slight reduction of cognitive control permits a modicum of judgmental behavior required to be able to attribute value to bottom-up intuitive insights. Associative thinking does require a sufficiently mature tacit knowledge base to associate with and as such should be reserved for expert training. Furthermore, studies linking long-term mindfulness practice with creativity also show that such practice induces a shift from left-brain rational to right-brain holistic thinking and features greater cognitive flexibility (Manna, 2010; Fabio, 2018; Luchini, 2025). This is considered generative (associative) creativity, rather than the analytical creativity that novices may experience.

The transition from novice to expert sensemaking introduces a shift in the type of mindfulness meditation practice required. Where novice training emphasizes developing cognitive control through *focused attention*, expert training should emphasize intuiting and sensing through meditation practices focused on *open awareness* (Berkowich-Ohana et al., 2017; Fabio & Towey, 2018). In Zen training, this is also described as direct experience (Pagnoni et al., 2008; Austin, 2013), which has for instance historically been trained through practices with Zen koans which cannot be solved rationally (Low & Purser, 2012; Li, 2014). Neuroimaging of both novice and expert Zen monks shows distinct differences where most notably open awareness meditation shows activation of both left (analytical) and right (holistic) brain regions (Manna et al., 2010), echoing similar findings observing brain activity during expert medical diagnosis of ambiguous situations (Van den Berg et al., 2020). The practice of open awareness implies, in contrast to focused attention, a relaxation of the mind. Interestingly, this aligns with experiential research showing that insight (i.e., "aha erlebnis") arises when one is in a state of relaxation such as under the shower, where right brain activity (holistic, associative) was observed prior to experiencing insight (Ovington et al., 2018).

Training such expert sensemaking requires sufficient exposure to situations that allow a candidate to experience ambiguity (in the context of aviation), practice open awareness and navigate the cognitive experiences of heuristic and holistic sensemaking. In contrast to novice sensemaking training focused on building tacit knowledge, expert training situations may feature a greater level of ambiguity and complexity that are far less proximal to familiar or even realistic situations. Where traditional pilot training emphasizing manual skills, procedural compliance and declarative knowledge is thereby limited to realistic situations (i.e. situations that can be expected to occur), sensemaking training may venture deeper into increasingly unlikely scenarios – a proverbial aviation *koan*. Such situations may also echo accident cases which featured significant ambiguity such as British Airways flight 009 that flew through volcanic ash, Quantas 32 which experienced 53 malfunctions[4] or Flight 1549 which featured a double engine failure

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[4] 53 malfunctions indicated by the A380's Electronic Centralized Aircraft Monitoring (ECAM) system.

shortly after departure. This may also develop an expert's intuiting through *creative action* where intuitive sensemaking is stimulated through unconscious somatic and sensorineural engagement with the aircraft, system or situation (Caruthers, 2007; Berkovich-Ohana et al., 2017; Stoycheva, 2025). In other words, taking action activates deeper sensemaking responses. A great example of this is showcased in Quantas Flight 72, in which a pitch control system reversal problem was only identified through the captain's intuitively *letting go* of the flight controls (ATSB, 2011). This is a similar experience as learning to solve a Rubik's cube through manipulation rather than solely through conceptualization, trimming sails when sailing with gusty winds or driving a car in busy traffic – our interactions with system and the environment *feed* our understanding as much as they are driven by it. As such, it is not only useful but may even be imperative that flight crews regularly interact with the aircraft and systems, in contrast to a role centered heavily on monitoring and automation management.

4.3. Novice-expert sensemaking teaming

The neurological differentiation between novice and expert pilot contributions to sensemaking offers a new perspective to the flight deck JCS. While an expertise gradient exists between captains and first- and second officers, the current interchangeability between pilot flying (PF) and pilot not flying (PNF) roles may need to factor in what sensemaking strategy the crew can best employ. For example, if a particularly ambiguous situation requires expert intuition, the more experienced crew member may need to engage in a diagnostic PNF role (or PF role, if the situation features flight controls problems in particular). The most experienced crew member would be the captain in most cases but may also be a first officer that has more experience on the aircraft type in question (Weick & Sutcliffe, 2011). In contrast, less ambiguous situations provide opportunities for less experienced crew members to response either procedurally or conceptually to develop their tacit knowledge through deliberate performance. Such novice-expert teaming has been suggested to be critical in developing expert intuition (Dane & Pratt, 2007).

Another crewing dynamic that may be relevant is operating a dual process approach with one crew member sensemaking conceptually, and the other sensemaking intuitively. This mirrors the brain's interaction between hemispheres, where conceptual analysis provides stronger diagnostic hypotheses and intuitive responses provide novel explanations for ambiguous and complex situations. Such a collaboration could be the subject of new neurologically informed problem-solving mnemonics that engage specific sensemaking strategies. This may be a way to systematically maintain sensemaking fluency in light of the comparatively low occurrence of ambiguous situations as proposed by Mohrmann (2026). Such an approach mirrors the harmonization of organizational mindfulness (Slagmolen et al., 2009) into currently hierarchal sociotechnical systems as proposed by Lintern & Kugler (2017).

Such advanced neurocognitive crew collaboration for systemic resilience to opacity introduces significant implications for the recent flight deck evolutions towards Reduced Crew Operations (RCO) (Malik & Gollnick, 2016; Sprengart et al, 2018; Schmidt & Stanton, 2020) and Human-Artificial Intelligence (AI) Teaming (HAT) (EASA, 2023; Lorrig & Daw, 2024; Kirwan 2025; Hörhager, 2025) which, respectively, remove and add to the cockpit cognitive space. The concept of RCO is difficult to reconcile with the above neuro-collaborative paradigm. This is because it either inhibits progressive expertise development (required for resilient operations) or significantly raises pilot expertise requirements which may result in a workforce continuity challenge (Harris, 2023). The possible expansion of supportive automation in the RCO pathway also risks a stronger re-activation of Klein's self-reinforcing complexity loop (Klein, 2011), which is the very *raison d'etre* for a more resilient Airmanship 2.0 concept. The emergence of AI in aviation also possibly introduces ripples in the cockpit JCS and may either exacerbate or mitigate systemic JCS brittleness. Novel human-AI teaming protocols which actively facilitate the human neurocognitive sensemaking mechanisms described in this article may indeed help reposition the future pilot toward Airmanship 2.0. Both RCO and HAT developments may prove to be critical topics for future research into sensemaking.

4.4. Possible evolutions of the training pipeline

To support the previously established neurocognitive differentiation between novices and experts, pilot training and development can/must exhibit a phased trajectory to provide the right sequence and separation in training these problem-solving skills over the course of a pilot's career. Table 3 shows the current training pathway for a commercial pilot and indicates how these programs could be modified to develop the neurocognitive concepts underpinning Airmanship 2.0. An expanded reconsideration of the training pipeline is provided in Appendix A.

Table 3. Overview of possible adaptations to the training regimen of a commercial pilot for sensemaking

(Current) Training Program	Possible adaptations
Pilot selection	▪ Evaluation of key sensemaking pre-requisites including self-reflection, basic emotional regulation skills and tolerance for ambiguity;
Ab-initio & Multi-Crew Coordination (MCC) training	▪ Mindfulness training (focused attention meditation); ▪ Emotional regulation training (e.g. startle and surprise recovery training); ▪ Scenario-based conceptual sensemaking training; ▪ Crew-coordination training in collaborative sensemaking strategies;
Type-Rating & Zero Flight Time Training (ZFTT)	▪ Practice type-specific conceptual problem solving;

Recurrent Training	▪ Recurrent training in sensemaking and emotional regulation (e.g. recurrent startle & surprise training);
	▪ Enhanced CRM training in collaborative sensemaking;
	▪ Adapted competency model:
	  ▪ Extending Leadership & Teamwork (LTW) and Situation Awareness (SAW) competencies with behaviors about metacognitive awareness;
	  ▪ Extending Problem Solving & Decision Making (PSD) competency with behaviors related to cognitive flexibility and hypothesis testing;
	▪ Practice in flight debriefings and *deliberate performance;*

Command Training	▪ Selection criteria should assess a pilot's abilities in conceptual sensemaking and potential for heuristic/holistic sensemaking; ▪ Training in heuristic and holistic (intuitive) sensemaking; ▪ Training in experiential learning (creative action);

Instructor training	- Ability to teach (collaborative) sensemaking activities; - Facilitation techniques specific to startle, mindfulness, and all three sensemaking modalities;
Examiner training	- Ability to evaluate (collaborative) sensemaking activities (ideally competency-based);

Several of the above changes are already being supported in the form of (voluntary) CBTA such as Evidence Based Training (EBT) and the Multi-Pilot License (MPL) program (ICAO, 2013; IATA, 2024; EASA, 2020). The coming years will also see CBTA developments trickle down the training pipeline from type-rating training through to ab-initio training, providing more opportunities for improved sensemaking training.

These developments provide a good foundation to introduce these new neurocognitive abilities for two reasons. First, competency-based training programs make use of more operationally relevant and realistic training with simulated Line-Oriented Flight Training (LOFT), thereby shifting the focus from *checking* to *training*. Second, they already feature significantly expanded performance criteria to include non-technical crew collaboration skills, which can be further expanded to fully encompass all the (meta-)cognitive abilities described in this paper.

The following section describes a study exploring these new neurocognitive frontiers in aviation training. As an example of bridging these neurocognitive abilities with the pilot competency framework, the case study in Section 5 explores the potential of mindfulness training to improve flight crew response to opaque, ambiguous situations in flight, as well as the challenges in pushing the envelope in training toward the neurocognitive domain.

5. Case study: Pilot mindfulness training

This section will outline the case study approach, results and research conclusions. Section 6 will reflect on the related challenges (and opportunities of neurocognitive training in aviation. The author was engaged to guide a large, western air cargo operator’s safety department in their exploration of ways to develop a High Reliability Organization (HRO), and in particular to identify opportunities to train their personnel in resilience behavior. A key element of HRO development was introducing mindfulness into the organization to improve organizational resilience. The use of mindfulness to support HRO’s has been explored earlier (Slagmolen et al., 2009; Weick & Sutcliffe, 2015). The study was performed in 2018 with the knowledge of the time.

This specific study explored whether mindfulness training could equip pilots to improve their flight safety performance on the following top safety priorities (at the time, unranked):

- Altitude deviation
- ATC complications/communication event
- Incursion/excursion event
- Speed deviation
- Navigation/position control
- Non-compliance with regulations, policies, procedures
- At-risk landings
- Unstable approaches
- Automation modes on go-around and landing

The mindfulness training intervention was aimed at developing pilots in the following neurocognitive skills:

- Emotional regulation,
- Non-judgement,
- Observing (focused attention),
- Open awareness (monitoring more sensory info/emotions/thought), and
- Cognitive flexibility (task/situation/concept switching)

To link these neurocognitive abilities to flight safety priorities, the study used a behavioral framework to bridge neurocognitive ability to flight safety. This framework employed the eight[5] ICAO core competencies, supplemented with “startle & surprise management” and “fatigue management” as two custom competencies, with their respective behavioral markers established by the research team. The choice for this compound behavioral framework was based on the most likely connections between flight operational safety and mindfulness training impact, as well as aligning to relevant industry training standards and human factors research. Each of these competencies was evaluated in its ability to bridge mindfulness with flight operations. This was done by ranking their (expected) response to mindfulness training, and in turn their (expected) impact on the safety priorities.

The first comparison linking competencies and their behavioral markers with *mindfulness training* used a Delphi-approach (Linstone & Turoff, 1975) involving only CBTA and mindfulness experts, to ascertain which competencies would be most positively affected by mindfulness training. The Delphi method overlays independent expert assessments, contrasts responses and drives for consensus where differences occur. The ranking is summarized in the “mindfulness ranking” column in Table 4. As this score was based on evaluating each competency’s behavioral markers on potential mindfulness impact, final scores were normalized against the different number of behavioral markers in each competency. The larger the percentage score, the greater its potential to be positively influenced by mindfulness training. The second comparison linking the competencies and their behavioral markers with *flight safety priorities* was performed via the Delphi method involving CBTA, safety and operational experts. The results are provided in the “Safety Ranking” column in Table 4. The “Average ranking” column is the average of the

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[5] This study engaged the eight ICAO core competencies in line with ICAO Doc 9995 (ICAO, 2013) which was the recognized pilot competency framework at the time. More recently, the industry recognizes a distinct ninth competency (“Application of Knowledge”) which was introduced by EASA and IATA.

two other columns and indicates which behaviors serves as the most robust bridge between mindfulness and the safety priorities and serves as the rank order for the table.

Table 4. Relationship of mindfulness to flight safety priorities via competencies (ranked by average rating)

Competency (*ICAO Competency)	Mindfulness ranking (Normalized)	Safety ranking (Normalized)	↓Average ranking (Normalized)
Problem Solving and Decision Making*	100%	100%	100%
Workload Management*	96%	95%	95%
Startle & Surprise Management	98%	85%	92%
Situation Awareness*	94%	81%	88%
Aircraft Flight Path Management (FPM) – Manual*	80%	92%	86%
Aircraft FPM – Automatic*	76%	91%	83%
Leadership and Teamwork*	85%	81%	83%
Communication*	86%	69%	78%
Application of Procedures*	49%	85%	67%
Fatigue Management	40%	91%	65%

Based on Table 4, the main research hypothesis to connect mindfulness and flight safety focused on those three competencies featuring the greatest connection to both factors (highest "Average Ranking" according to Table 4), and was stated as follows:

"Mindfulness training is expected to have a positive effect on the operator's flight safety through supporting and enhancing the following flight operational behaviors/core competencies: Problem Solving & Decision Making, Workload Management, Startle & Surprise Management."

5.1. Study method

The study explored this hypothesis by comparing flight safety performance between two groups: a control group without mindfulness training and treatment group with mindfulness training. The treatment consisted of two months of mindfulness training prior to a performance evaluation in a simulator scenario. The control group was not offered a placebo training; they represented the current state of the operator’s flight crew proficiency. Each group initially consisted of 15 crews (30 pilots), all from the same multi-crew long haul fleet, with the two groups balanced as much as possible for rank, age and flying experience.

5.1.1. Mindfulness training and evaluation scenario

The mindfulness training was developed by the mindfulness training organization and was tailored toward the operator’s flight operations, in collaboration with the operator’s flight operations experts. This tailoring explicitly linked mindful behavior with challenges and experiences in and around the flight deck context.

The mindfulness training consisted of two parts. The first part was a face-to-face training day with mindfulness trainers at the operator’s training center. This served as a kickoff to ensure that mindfulness practices were learned correctly at the onset. The second part was a series of online coaching sessions to check-up with candidates and reinforce the training for a period of two months. This was supported by a biometric feedback device, the Stanford-developed Spire Stone (Miller, 2017). The Spire Stone measured a candidate’s breathing depth, breath frequency and physical activity to distinguish a measure of three mental states (calm, tense and focused). Through a Bluetooth connection with their phone, candidates in the treatment group received alerts and relaxation tips when tense breathing was detected. The Spire device was provided to all candidates who participated in the study to collect biometric data, but the alerting functionality was only enabled for the treatment group. The training and provision of biofeedback was kept secret to pilots in the control group to avoid bias and self-training in that group. After completion of all simulator performance evaluations, the control group was offered the same mindfulness training, as well as the (uninhibited) Spire Stone device.

Safety performance was evaluated in a simulated flight scenario designed to challenge the bridging behaviors in Table 4, with a strong emphasis on *Problem Solving & Decision Making*, *Workload Management* and *Startle & Surprise Management*. The scenario featured a short night-time repositioning flight of a wide-body aircraft from the operator's base to a nearby airfield about 300 nautical miles away. The following is a brief synopsis of the scenario. Figure 3 shows a visual representation of this scenario.

> *The scenario begins as most flights with this operator: the aircraft is parked at the gate and shut down. The crews are provided all the regular preflight briefing material including aircraft state, weather and routing. They have about 30 minutes to review the paperwork, which is standard. Weather at the departure field is 5 miles of visibility, overcast at Flight Level (FL) 100 with cloud tops at FL260 with some thunderstorms brewing underway (not unusual for this region). The aircraft features a failure of the Hydraulic System Controller, which has an "inoperative" sticker on the left side of the hydraulic controller. This item does not restrict the aircraft as per the Minimum Equipment List (MEL). The crews receive a last-minute departure runway change as an initial mild disruption. Normal departure, climb and (short) cruise. Weather at the destination airfield has deteriorated significantly, with several runways closed for landing due to a storm cell that is passing, the crews are "forced" to divert to another more suitable airfield a bit further away. The wind at this alternate airfield is 170/15 gusting 22, cloud base at 3,500ft and 7 miles visibility. There are towering cumulus clouds in the area. Upon descending into the diversion airfield, the flight is cleared for the runway featuring 90 degrees crosswind at 15 knots gusting 22 knots, close to the aircraft crosswind limitations. At 2,400ft altitude during the approach, the anti-skid fails for one of the landing gears (another hydraulic system*

failure), which requires a go-around given the cross-wind conditions. Missed-approach procedures require them to turn left, to the North. If crews elect to continue on the runway heading instead of turning, ATC will request this for traffic avoidance reasons. After this initial turn, crews turn further left for a second approach, and are then struck by lightning (a startle event, during a higher workload situation). Autopilot and auto-thrust systems disconnect as a result. Crews are given time to react and plan as they see fit, and are provided radar vectors if requested. Crews may elect to choose runway 9L as it is longer and more appropriate for the cross-wind conditions. The remaining approach, landing and taxi-in are uneventful to end the scenario with a successful flight (to avoid negative training).

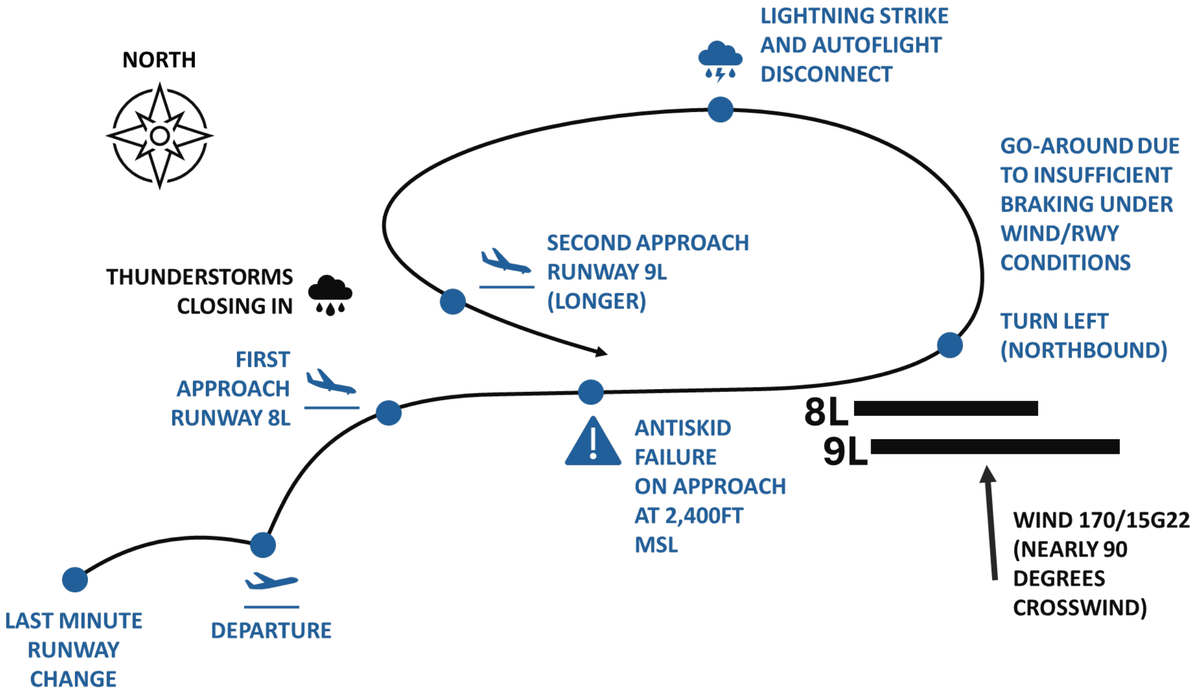


Figure 3. Sketch of flight simulation scenario

The scenario duration was approximately 45-60 minutes. To maximize immersion, crews were requested to arrive in uniform, perform all normal briefing items, Standard Operating Procedures (SOP) and check items as they would normally do in an actual flight, and to not treat the simulator as a training opportunity. There was one simulator instructor present to operate the simulator and scenario events, but he/she did not intervene with crews at any point. Despite this scenario featuring many more crew challenges than a normal flight, great care was taken such that the slow escalation, temporal spread and specific timings of events were such that crews were drawn in (immersed) and not bluntly overloaded. Several validation sessions including pilots not involved in the scenario design facilitated the fine tuning of this scenario and event timings.

5.1.2. Mindfulness data

The study collected two types of data: mindfulness measures and flight safety performance measures. Mindfulness data were collected at the beginning of the study and during the treatment period of two months, to determine whether the treatment group featured a different level of mindfulness (post-treatment) than the control group. Flight safety performance data were collected to determine if the treatment group also outperformed the control group in the flight operational scenario. All data were collected in a double-blind fashion to avoid evaluator bias.

Data on mindfulness consisted of self-reported scores via two surveys and biometric data from the Spire Stone device, collected for both control and treatment groups. Self-reported scores were based on an 86-question survey administered before the mindfulness training and immediately after the simulator session (Survey 1). A shorter 31-question survey was administered after each actual operational flight the crew member flew during the two-month training period tracked the development and application of mindfulness techniques in flight operations (Survey 2).

Both surveys asked candidates to what extent they recognized themselves in specific statements or had particular experiences related to the following five mindfulness measures:

- Focus (Scale 1-10),
- Communication quality (in the flight deck) (Scale 1-10),
- Emotional intelligence (Scale 1-5),

- Fatigue (Scale 1-5), and
- Work-life balance (Scale 1-5)

The biometric mindfulness data provided insights into deeper changes to candidate mental states over the course of the preceding two months. Participants were encouraged to wear the Spire device as much as possible, although it was ultimately voluntary. Data was collected about device usage (minutes per day) as well as the ratio of specific inferred mental/physical states during device usage. The biometric data consists of the following metrics:

- Total minutes worn (group total minutes per day),
- Focus ratio (group average ratio per day, same for other ratios),
- Calm ratio,
- Tense ratio,
- Activity ratio, and
- Sedentary ratio

5.1.3. Flight safety performance data

Flight crew performance data were collected from observations of crew behavior during the simulated scenario, supported by facilitated debriefings after the simulator scenario. The Desired Flight Crew Performance (DFCP) method (Field et al., 2016) was used to provide a fair basis of comparing multiple alternative crew resolution strategies in this scenario. The DFCP framework for this study was developed in collaboration with the operator’s flight operational experts and human performance experts from the participating research institute. Each performance item was unambiguously described and marked as “observed” or “not observed”. Each performance item was phrased as a positive, desired behavior, so marking it as “observed” results in a higher valuation of that crew’s performance. By structuring observations and avoiding SME interpretations, the effect of subjectivity is reduced considerably.

The DFCP framework featured 53 observable items, which were graded “live” during each scenario run, by a type-rated examiner. Post-scenario debriefing was also facilitated by the same examiners and provided further resolution to simulator observations concerning flight crew awareness, decisions, self-awareness, experiences and considerations. These debriefings were recorded and transcribed to supplement a crew’s DFCP scores with context and storyline. The observing examiner did not know whether the crew was from the treatment or control group to avoid study bias.

Crew DFCP scores were further divided per flight phase and per competency (across the entire scenario). The division per flight phase allowed the data analysis to investigate whether the experiment groups featured different performance in any specific segments of the scenario (which may feature specific challenges). The division per competency was an alternative approach to determine if there were between group differences in DFCP items related to one competency or another. The distribution of the 53 DFCP items across the study’s competency framework was determined with the support of three independent SME’s: an active-duty pilot, a CBTA expert and a type-rating examiner. In this cross-reference, the Fatigue Management competency was not attributable to any DFCP item, explainable by the fact that it was also not one of the design focus points for the simulator scenario. Hence, in the DFCP results there is no fatigue competency measure presented.

5.2. Study results

Unfortunately, the research team experienced significant (and unexpected) challenges in retaining participants for the full duration and scope of the study. The explorative and progressive nature of this research initiative was difficult to place in both the operator’s operational and training contexts. In particular, the messaging about the study rationale and desired outcomes turned out to negatively affect pilot interest and motivation to participate. Many crews disengaged before the final performance evaluation in the simulator, with a few cases completing the simulator flight but whose results were not admissible due to specific union-company agreements.

This is a key learning opportunity for future attempts in such neurocognitive and emotionally sensitive training. An overview of responses and participation is provided in Table 5. Instead of the intended 30 crews (60 individuals), only nine crews completed the entire experiment including the simulator scenario (five treatment group crews and four control group crews).

Table 5. Response rate for mindfulness and performance measures

Measure	Control group	Treatment group
Survey 1 pre-study	23 individuals	32 individuals
Survey 1 post-study	4 individuals	7 individuals
Survey 1 both pre- and post-study	2 individuals	2 individuals
Survey 2 (operational)	59 submissions 12 individuals	161 submissions 29 individuals
Spire biometrics	Varying number of individuals, declining usage	Varying number of individuals, declining usage
DFCP	4 crews (8 individuals)	5 crews (10 individuals)

5.2.1. Mindfulness survey results

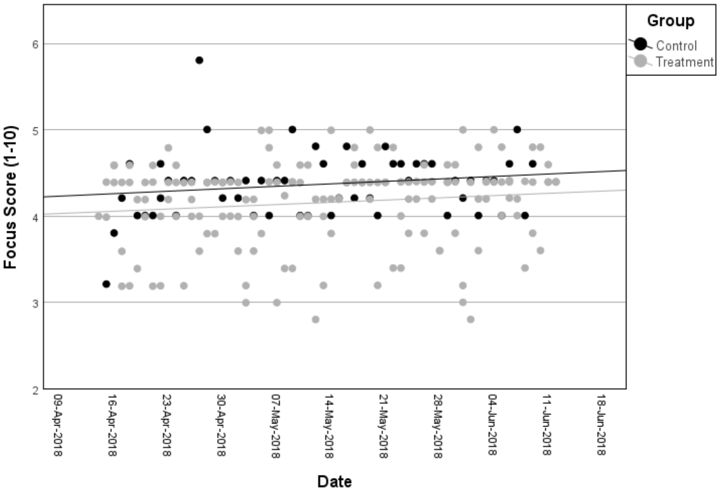
Initial mindfulness scores from Survey 1 indicated an equivalent level of mindfulness for both control and treatment groups prior to treatment. However, due to the rapid decrease in study participation, evaluating the longitudinal training effect with pre- and post-study Survey 1 responses was not feasible due to the very low response rate to the exit-survey: only four individuals (two in each treatment group) completed both pre- and post-surveys. As such, Survey 1 results are not investigated further in this study.

Survey 2 results did have sufficient data to perform between-group evaluations. A very small number of extreme outliers were removed. Shapiro-Wilk testing indicates these metrics should be treated as non-parametric. Non-parametric Mann-Whitney U Test results for between group differences are provided in Table 6. A Benjami-Hochberg False Discovery Rate (FDR) *p*-adjustment is applied to each test family and critical q is reported as such. Statistically significant results ($q \le 0.05$) are indicated, as well as near-significant results ($p \le 0.05$ but $q > 0.05$), and strong trends ($p>0.05$, effect size >0.5). Furthermore, to investigate temporal between group differences (i.e., changes of scores over time), an ANCOVA significance of the group interaction term is also reported. Communication and EQ ratings are statistically significantly higher in the treatment group, although there is no difference between the groups over time. Fatigue and work-life balance scores are not statistically different between the groups. Figure 4 shows the survey response data plots and Figure 5 shows the respective box plots.

Table 6. Survey 2 between group differences (Mann-Whitney U Test)

Metric	Control Group mean rank	Treatment Group mean rank	Exact[6] significance *p* (two-sided)	ANCOVA significance *p*
Focus	131.23	96.88	<0.001***	0.142
Communication Quality	64.00	117.66	<0.001***	0.001***
Emotional intelligence	84.68	113.07	0.003***	0.402
Fatigue	119.35	103.20	0.092	0.866
Work-Life Balance	97.43	113.67	0.096	0.435

*** $q \le 0.05$, $p \le 0.05$, $q > 0.05$**, *$p > 0.05$, effect size $r > 0.5$



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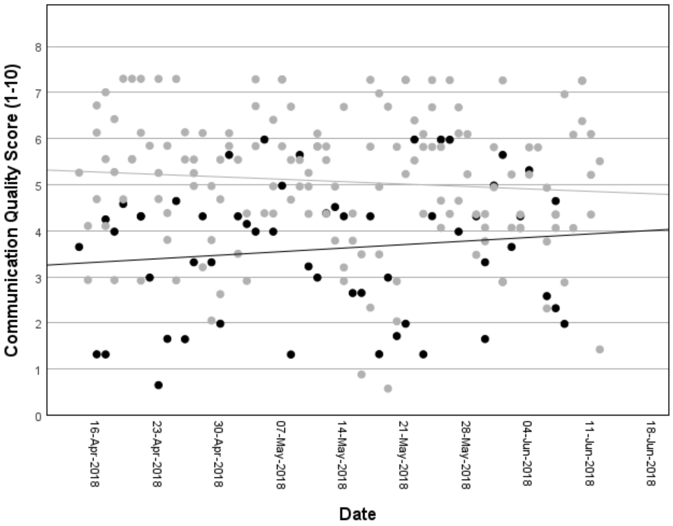
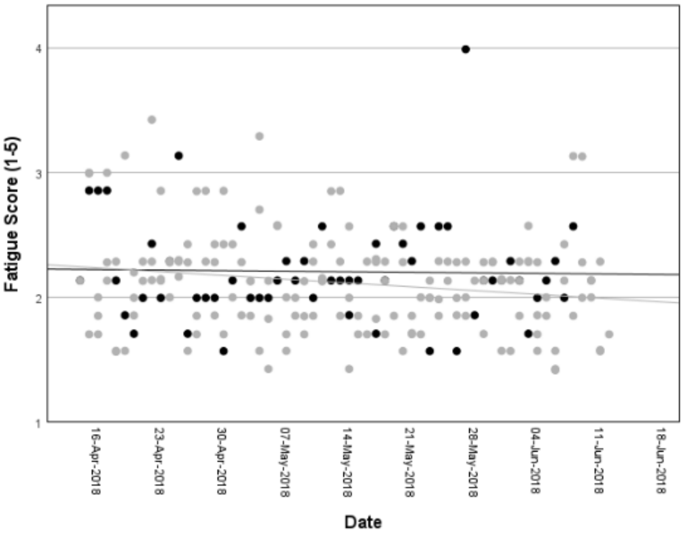
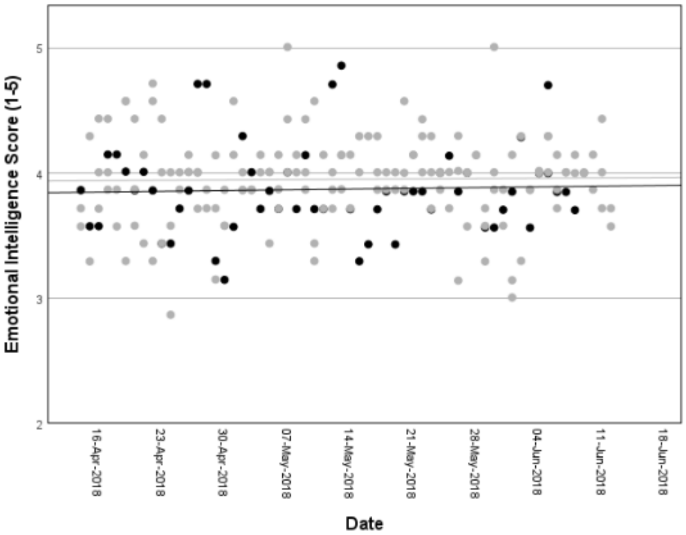
[6] Customary for Mann-Whitney U-Testing with sample sizes smaller than 20.


Communication Quality Score (1-10)
0
1
2
3
4
5
6
7
8
16-Apr-2018
23-Apr-2018
30-Apr-2018
07-May-2018
14-May-2018
21-May-2018
28-May-2018
04-Jun-2018
11-Jun-2018
18-Jun-2018
Date


Fatigue Score (1-5)
1
2
3
4
16-Apr-2018
23-Apr-2018
30-Apr-2018
07-May-2018
14-May-2018
21-May-2018
28-May-2018
04-Jun-2018
11-Jun-2018
18-Jun-2018
Date


Emotional Intelligence Score (1-5)
2
3
4
5
16-Apr-2018
23-Apr-2018
30-Apr-2018
07-May-2018
14-May-2018
21-May-2018
28-May-2018
04-Jun-2018
11-Jun-2018
18-Jun-2018
Date

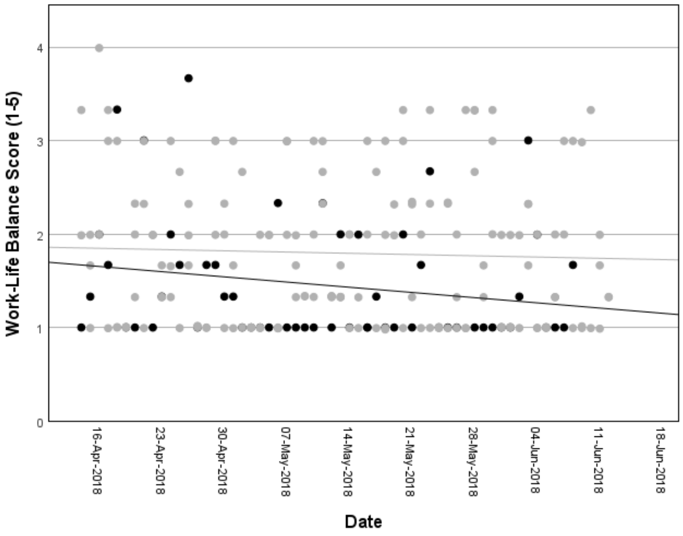
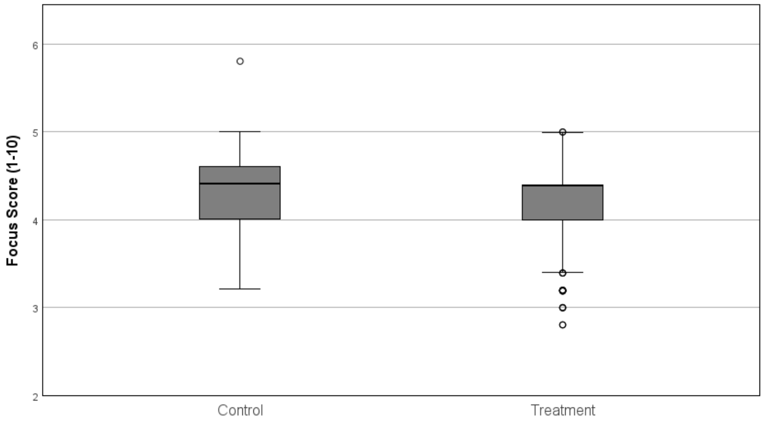
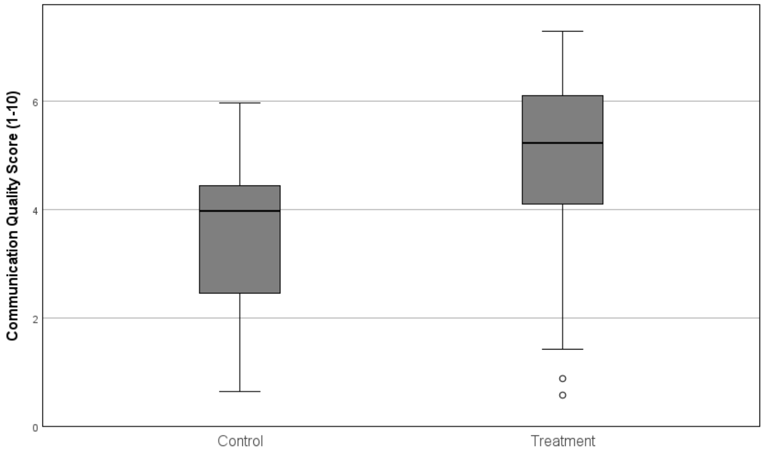


Figure 4. Data plots for Survey 2 metrics.





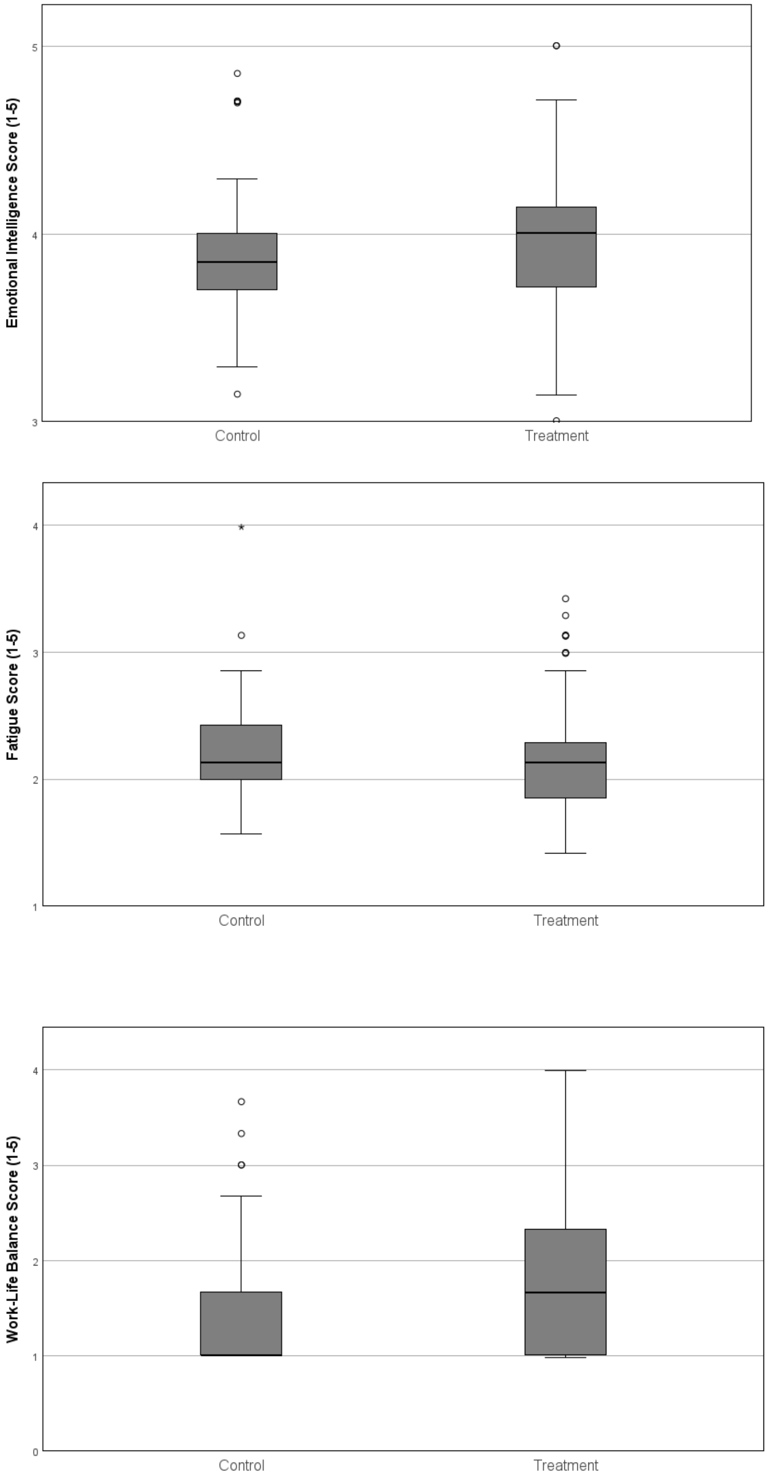


Figure 5. Box plots for Survey 2 metrics.

5.2.2. Mindfulness biometric results

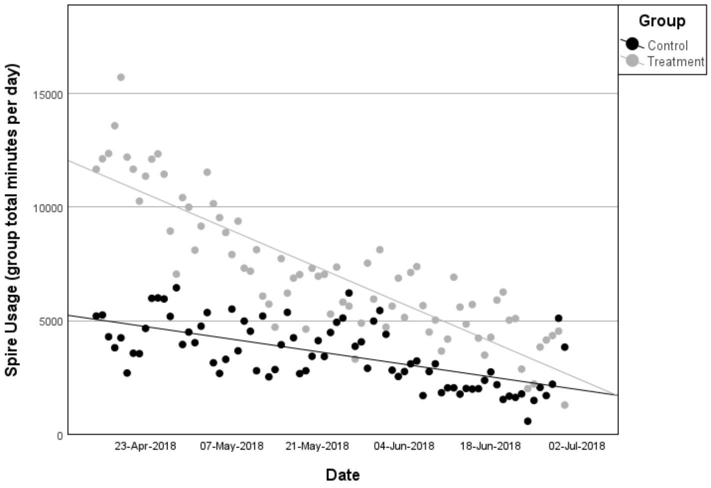
Spire data from all experiment participants also featured non-parametric data and was subject to the same Mann-Whitney between group testing as survey data. There are no outliers to be removed, likely attributable to the non-subjective nature of the data. Spire data also suffered a sharp decline from 15,000 total minutes for the treatment group at the start to less than 5,000 minutes by the end of the study.

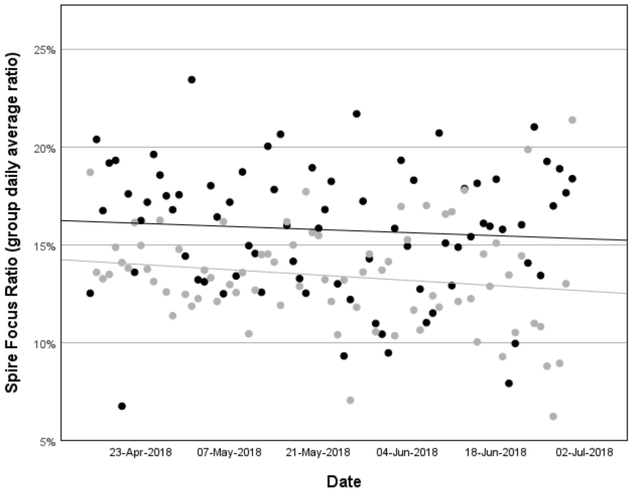
Results in Table 7 show significantly higher usage, calm and sedentary scores in the treatment group, as well as significantly lower focus scores. Slope analysis shows that the control group featured significantly different changes over time for usage score (slower decline) as well as activity scores (increasing) and sedentary scores (decreasing). The latter two are likely strongly coupled. The increased scores in calm and decreased focus provides some evidence of training effect, possibly in terms of open-awareness rather than focused attention. Spire data and box plots are provided in Figure 6 and Figure 7 respectively.

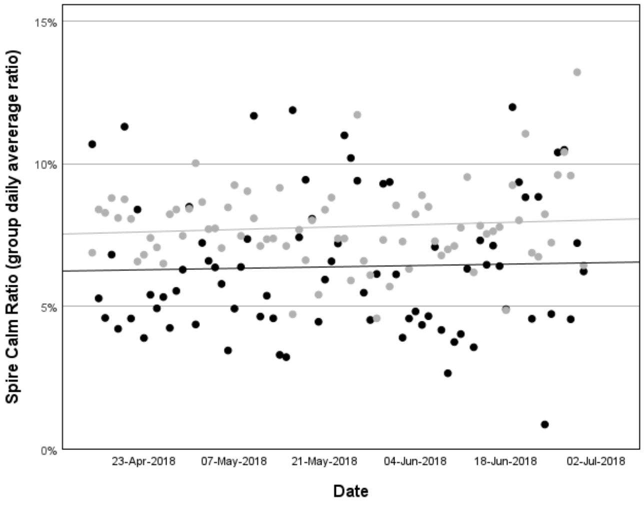
Table 7. Spire biometric data between group differences (Mann-Whitney U Test)

Metric	Control Group mean rank	Treatment Group mean rank	Exact significance *p* (two-sided)	ANCOVA significance *p*
Spire Usage	41.61	86.66	<0.001***	<0.001***
Focus Ratio	83.00	56.03	<0.001***	0.379
Calm Ratio	49.05	81.16	<0.001***	0.371
Tense Ratio	69.39	66.10	0.630	0.647
Active Ratio	73.09	63.36	0.153	<0.001***
Sedentary Ratio	57.77	73.70	0.012***	<0.001***

*** $q \le 0.05$, $p \le 0.05$, $q > 0.05$**, *$p > 0.05$, effect size $r > 0.5$


Group
Control
Treatment
Spire Usage (group total minutes per day)
15000
10000
5000
0
23-Apr-2018
07-May-2018
21-May-2018
04-Jun-2018
18-Jun-2018
02-Jul-2018
Date


Spire Focus Ratio (group daily average ratio)
25%
20%
15%
10%
5%
23-Apr-2018
07-May-2018
21-May-2018
04-Jun-2018
18-Jun-2018
02-Jul-2018
Date


Spire Calm Ratio (group daily avererage ratio)
15%
10%
5%
0%
23-Apr-2018
07-May-2018
21-May-2018
04-Jun-2018
18-Jun-2018
02-Jul-2018
Date

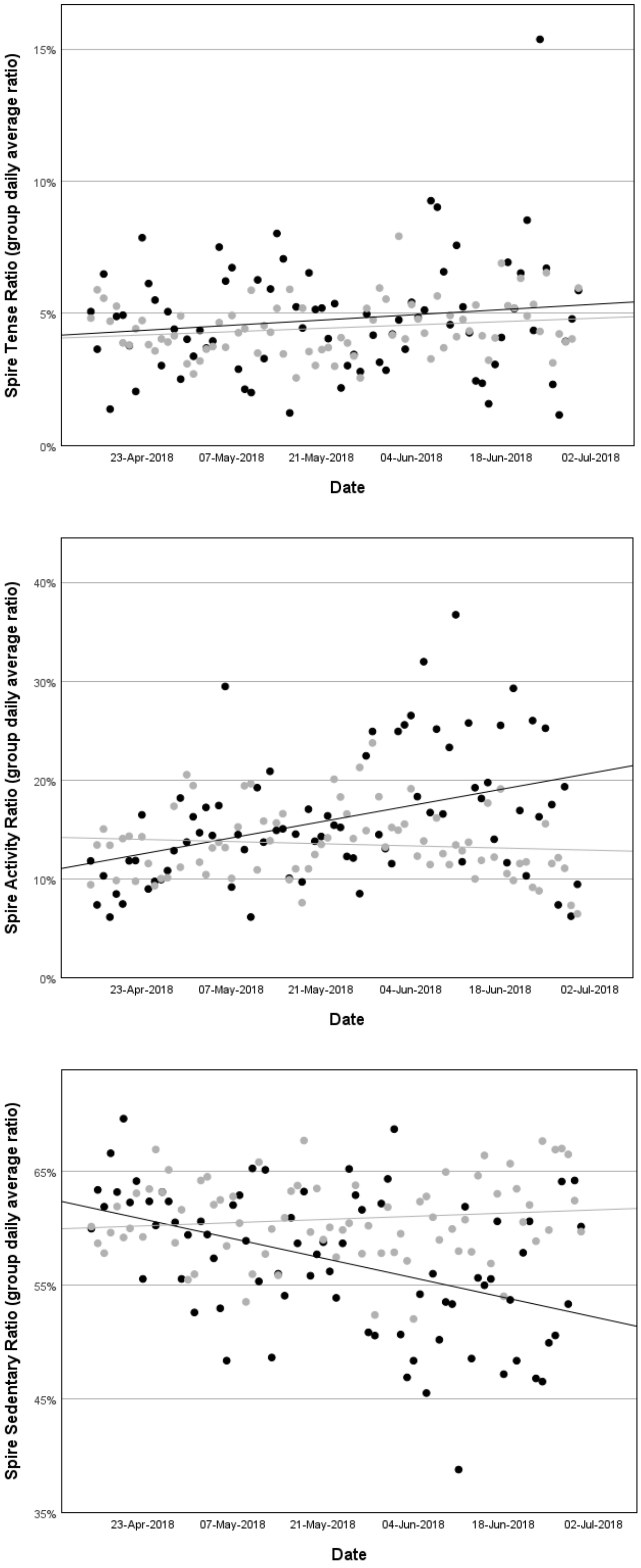
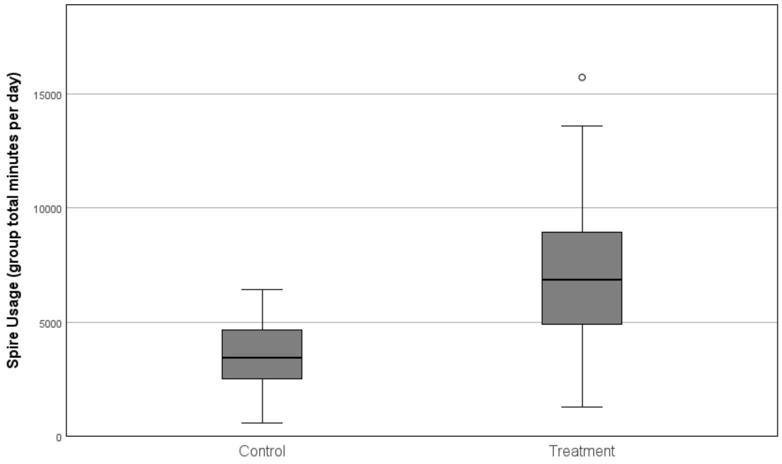
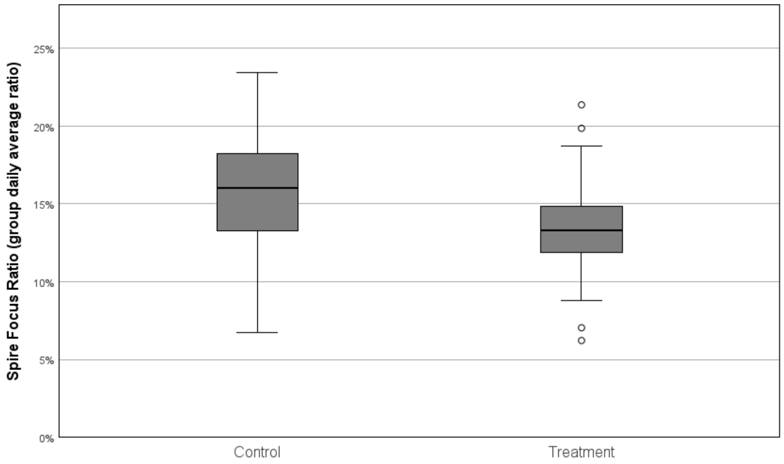
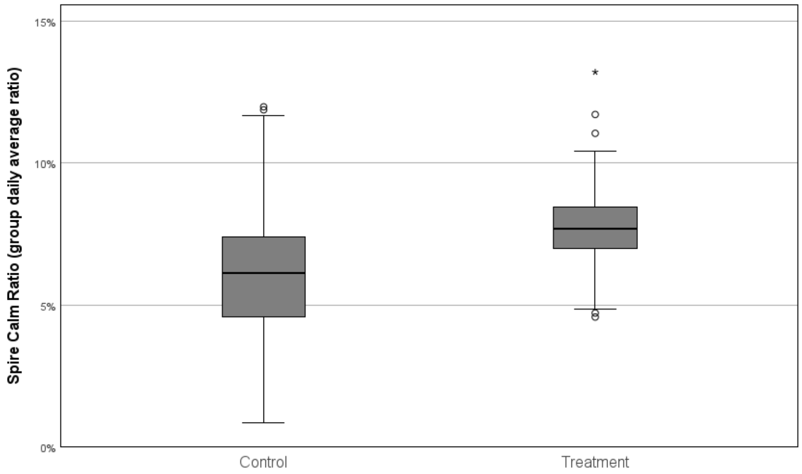


Figure 6. Data plots for Spire biometric data.


Spire Usage (group total minutes per day)
15000
10000
5000
0
Control
Treatment


Spire Focus Ratio (group daily average ratio)
25%
20%
15%
10%
5%
0%
Control
Treatment


Spire Calm Ratio (group daily average ratio)
15%
10%
5%
0%
Control
Treatment

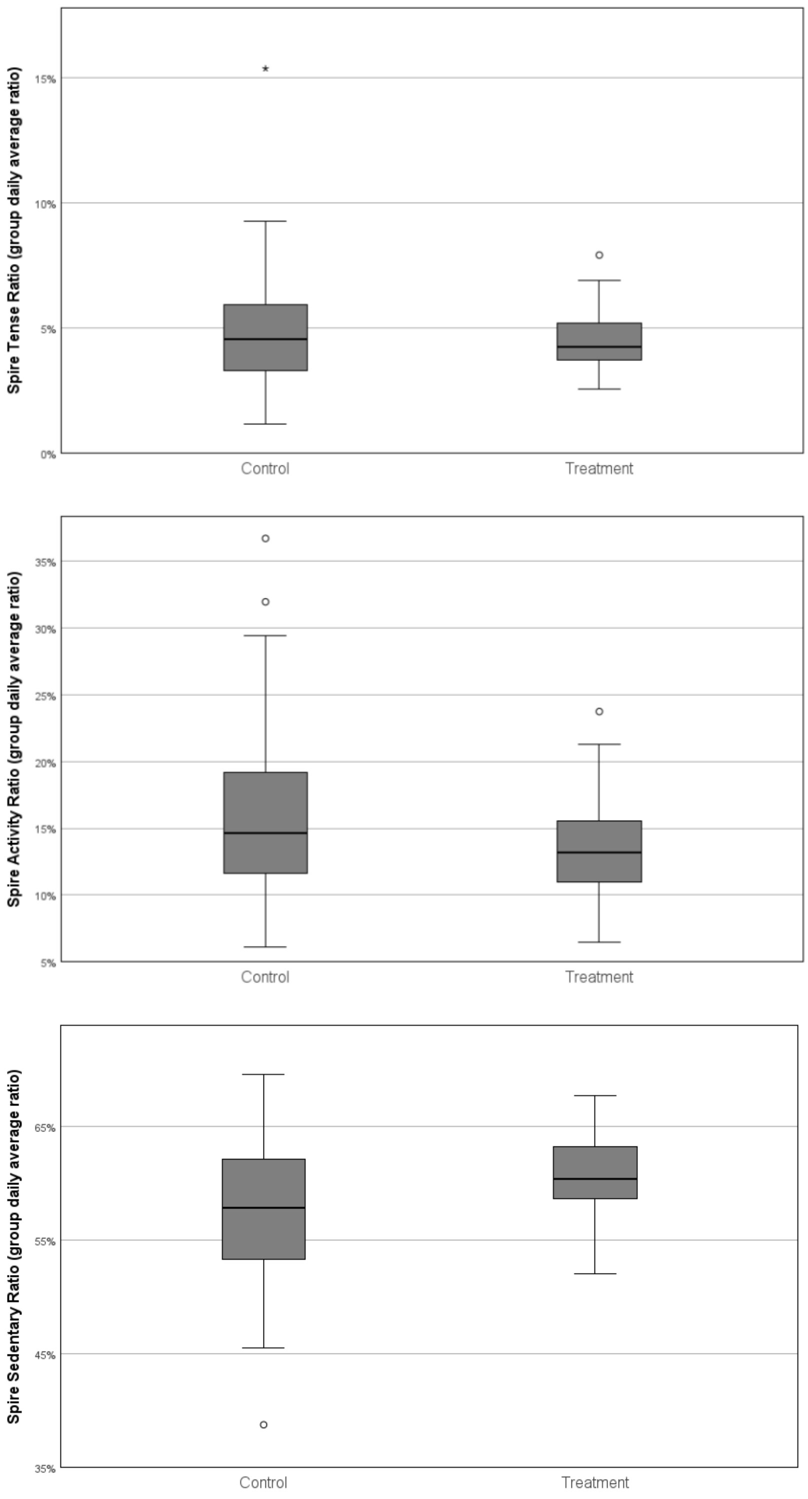


Figure 7. Box plot for Spire biometric data.

5.2.3. Flight Safety Performance Results

Wilks-Shapiro test for normality indicates that several DFCP (sub)indices are non-parametric. Between-group differences are evaluated with Mann-Whitney U Testing with significance tested at the 0.05 level, BH FDR correction and effect size monitoring. Table 8 and Table 9 provide the between group comparison results for all DFCP (sub-) indices for flight phase and competencies, respectively. A higher mean rank indicates higher performance. Despite generally hypothesizing that the treatment group will feature higher performance, a two-tailed significance test is still appropriate because it is unknown whether there may be (unintended) reversal effects where mindfulness treatment may negatively impact a competency or flight phase.

Performance in the holding/startle event was the only DFCP metric featuring a significant difference between the group (treatment group outperformed the control group), although the test strength was not strong enough to survive FDR *p*-adjustment. Looking across all metrics, in most cases the mean rank performance of the treatment group was higher than the control group, but these differences are not significant despite some effect sizes (“After Landing” phase, and “Problem Solving & Decision Making” and “Startle & Surprise Management” competencies) suggesting that non-significance may be the result of a limited study power with N = 9 for DFCP comparisons. Figure 8 and Figure 9 show the box plot distributions for both DFCP sets.

Table 8. Mann-Whitney U Test between group comparison of DFCP scores per flight phase

DFCP Flight Phase Measures	Control Group mean rank	Treatment Group mean rank	Exact significance *p* (two-sided)
Total	3.88	5.90	0.286
Paperwork	5.00	5.00	1.000
Preflight Flight deck	5.38	4.70	0.730
Taxi	5.00	5.00	1.000
Takeoff/Climb	5.00	5.00	1.000
Cruise	4.13	5.70	0.413
Descent	3.75	6.00	0.286
Approach	4.38	5.50	0.556
Go Around	5.38	4.70	0.730
Holding/Startle Event	2.88	6.70	0.032** (r = 0.732)
Approach	4.25	5.60	0.556
Landing	4.38	5.50	0.556
After Landing	3.50	6.20	0.190* (*r* = 0.586)

**** q ≤ 0.05, p ≤* 0.05, *q > 0.05**, *p > 0.05, effect size r > 0.5*

Table 9. Mann-Whitney U Test between group comparison of DFCP scores per competency

DFCP Competency Measures	Control Group Mean Rank	Treatment Group Mean Rank	Exact-significance p (two-sided)
Application of Procedures	4.75	5.20	1.000
Communication	3.63	6.10	0.190
Aircraft FPM - Automatic	4.38	5.50	0.556
Aircraft FPM - Manual	4.38	5.50	0.556
Leadership and Teamwork	4.88	5.10	1.000
Problem Solving and Decision Making	3.38	6.30	0.111* (r= 0.545)
Situation Awareness	4.25	5.60	0.556
Workload Management	4.13	5.70	0.413
Startle & Surprise Management	3.75	6.00	0.286* (r= 0.563)

**** q ≤ 0.05, p ≤* 0.05, *q > 0.05**, *p > 0.05, effect size r > 0.5*

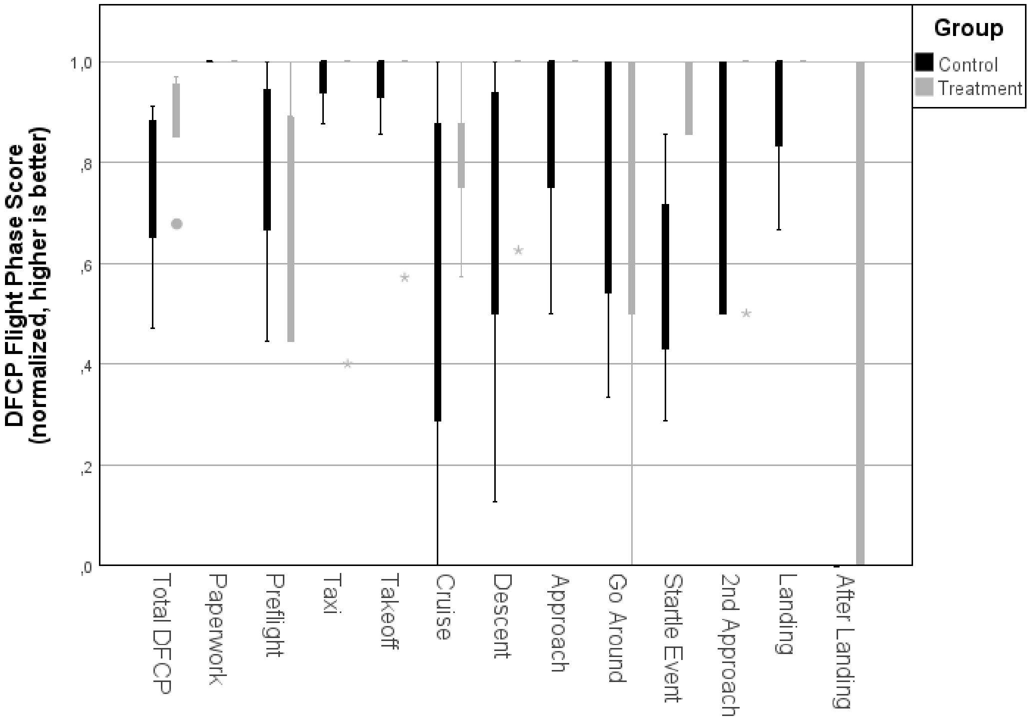


Figure 8. Box plot comparison of group DFCP scores per flight phase (in scenario sequence)

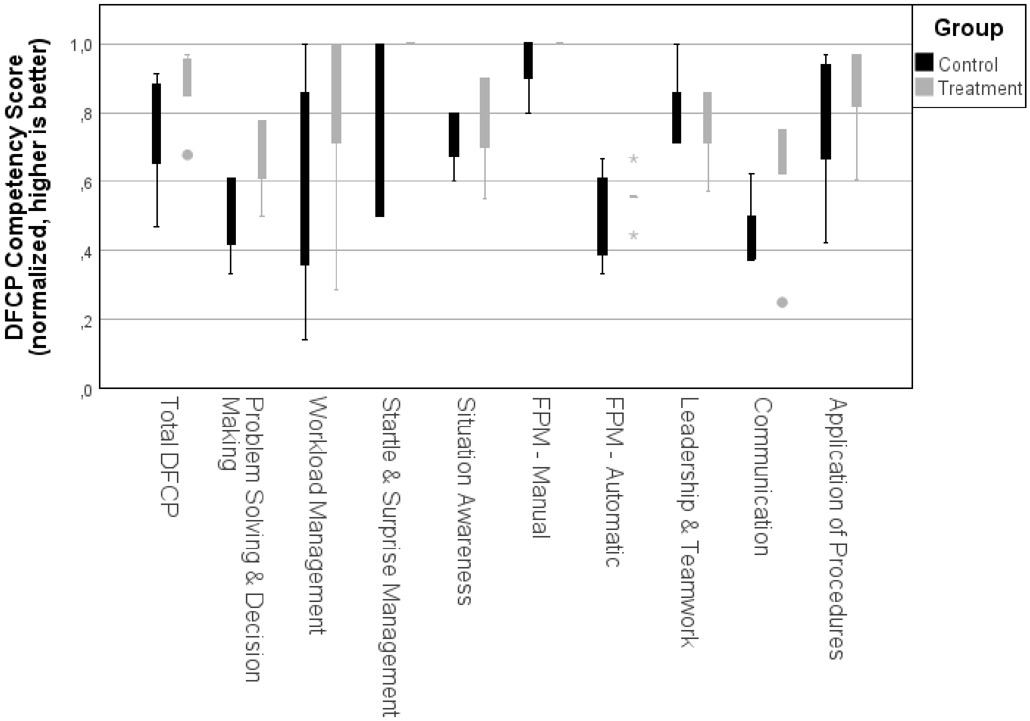


Figure 9. Box plot comparison of group DFCP scores per competency (in order of Table 4, excluding fatigue management)

5.3. Study conclusions

The study provides initial, albeit tentative, evidence that mindfulness training may improve pilot management of opaque situations. Some differences in neurocognitive ability were identified between the study groups by means of data from Survey 2 and biometric Spire data. The treatment group featured significantly higher scores for communication quality, emotional intelligence and calmness, as well as significantly lower focus scores and ratios. Furthermore, biometric data also indicated lower activity ratios and higher sedentary ratios in the treatment group. These results suggest that there may be a training effect present.

In terms of competencies, the three “bridging” competencies which were hypothesized to have the strongest treatment effect (“Problem Solving & Decision Making”, “Workload Management” and “Startle & Surprise Management”) all feature a treatment group showing a higher mean performance than the control group, although not statistically significant. The flight phase DFCP metric for the startle event did show a significant difference (pre-FDR correction), where the treatment group outperformed the control group. Furthermore, the strong trends for “Problem Solving & Decision Making” and “Startle & Surprise Management” competencies where treatment crews outperformed control crew align with the study hypothesis. These results, while encouraging, cannot confirm that any training effect established also transferred to the flight operational context, and required a more powerful study to confirm beyond the False Discovery Rate (FDR).

The greater calmness of the treatment group may be related to improved open awareness and reduced focused attention, which aligns with the neuroscience of expert holistic sensemaking in the context of ambiguity (which startle and surprise induces). This causal link is tentative but may be reason for a targeted study into such meditation nuances. The increased EQ may also have supported emotional regulation to down-regulate the amygdala and limbic arousal in response to startle and surprise and improve crew response during the startle event. However, this causal link between EQ, calm and focus with startle management is also tentative, as the study featured several limitations which must be observed before such inference can be confirmed.

The study featured three notable limitations: declining, voluntary participation, lack of within group analysis and limited ability to stratify mindful ability. The progressive decline in participation and voluntary nature of Survey 2 reporting and Spire usage introduces demographic skewing (e.g., particularly engaged or disengaged individuals significantly add or subtract to the data pool). The decline in participation also prevented longitudinal evaluation of Survey 1 which was intended to provide greater resolution in pre- and post-study mindful ability.

The second limitation to perform a between group analysis was in part the results of too many incomplete participations, where only a group-based comparison between mindfulness scores and flight safety performance scores is possible (with significant reservations concerning small sample sizes). Future studies may be improved by means of a within group analysis to establish direct correlation between mindfulness metrics and flight safety performance metrics. Such an approach partially mitigates reduced participation risks and provides a stronger inferential framework around training transfer to flight operations, while still able to evaluate a training effect with between-group analyses.

This leads to the third limitation where individual mindful ability and openness to mindfulness training was not accounted for[7]. An individual crew member's level of mindfulness does not only vary due to exposure to this experiment's mindfulness training but may also be affected by spiritual predisposition, prior meditation experience, personality, motivation (particularly in adult learning contexts) and training methods. Mindfulness training can realize some short-term changes in cognition (Remmers et al., 2015; Berkovich-Ohana et al., 2017), but in many cases neuro-cognitive changes are observed after extended practice (Marchand, 2008; Fabio & Towey, 2018). Studies limited in training capacity and time may feature

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[7] Note: The groups were balanced in terms of expertise, flight experience, gender and age.

stronger effects if participants are selected and trained based on their mindful ability and openness (or indeed lack thereof), as this provides a stronger stratification to correlate flight safety with.

Other confounding effects that may have played a role in this study are participant mindset and context (e.g., awareness of it being a study focused on mindfulness), small sample sizes random effects and external factors such as fatigue during some simulator sessions outside of the circadian daytime. As such, the results of this study – although promising – are presented in the context of above limitations and cautions.

6. Discussion

The shift to a new model for airmanship to facilitate sensemaking to manage opacity is necessary to mitigate the growing brittleness of the aviation system. However, the requisite cultural change in the aviation industry to enable this shift is not without its challenges. At its core, the aviation industry's culture is rooted deeply in a sense of control and predictability, which has matured and functioned well for over a century. To acknowledge that one might not have that fundamental control in the face of current and future system complexity and accept the opacity and ambiguity it conjures, goes against deep-seated beliefs and existing habits in training, design legacies, oversight practices and judicial structures. There are not many engineers and pilots that are willing to admit they're "not sure": yet being comfortable and feeling competent despite having such doubts is precisely the deeper change advocated here. Schoemaker (2004) underscores the reality that highly complex, highly uncertain situations require us to challenge the conviction (rather: illusion) of total (cognitive) control and appreciate the very real limitations of deterministic strategies rooted in that conviction. In other words, growing a tolerance for ambiguity.

The mindfulness training case study presented in this article provides a first-hand account of the challenges in changing this mindset and "heartset". In hindsight, this was due to the study being leveraged in personal vulnerability, and insufficient connection with the study's population to effectively navigate these sensitivities. The neurocognitive mechanisms underpinning Airmanship 2.0 are nearly all possibly quite personal in nature, and future studies in this area are advised to mitigate the risks of disengagement by explicitly managing a safe learning and evaluation environment, while carefully monitoring the perception of such studies. Ironically, Airmanship 2.0 makes the case of *empowering* particularly human abilities, rather than diminishing the role of the pilot. However, this intention must be made clear to participants in the study, to distinguish itself from the hubbub arising from more contested cockpit evolutions such as RCO and HAT.

Another important reflection from this case study pertains to the contextualization of the mindfulness (or neurocognitive) training, particularly when dealing with a "hardened" professional such as commercial pilots in a highly procedural, specialized and deterministic domain. The gap between current flight operations and Airmanship 2.0 practices is considerable, and proper *contextualization* is essential to embed the desired neurocognitive sensemaking behaviors into modern flight training and operations. Techniques such as scenario-based training, peer-to-peer facilitated debriefing and redefined sensemaking and decision-making strategies may be effective to allow pilots to anchor new neurocognitive abilities into their routines and mindsets. Principles of adult learning such as self-motivation, relevance to own work and engagement of one's own knowledge and experience are very effective techniques to maintain interest and motivation (Henley, 2017) despite the possibly confrontational, personal and emotional nature of the training new (meta-)cognitive abilities. Such training also requires a safe environment free of judgment and instructors versed in the neurocognition of sensemaking. Within aviation, such advanced, deeply engaging training contexts are currently rare, although a recent publication (Van Leeuwen, 2024) provides an example of such explorative learning.

Beyond operational research into these mechanisms, this shift to foster a learning function implies changes in how the pilot is perceived by aircraft and system designers, training organizations, regulations and the pilot community itself. Section 2 described the fundamental *assumption* that pilots are always in control regardless of the situation they experience. A departure from this assumption may require a change in the type of persons that are comfortable within this less deterministic context. Pilots who enjoy the predictable, compliant and relatively limited nature of the existing pilot role may not be able to motivate or engage themselves to fulfill the learning function in the proposed new pilot role. Such changes in pilot qualification criteria must balance considerations in pilot drafting and retention to ensure that the pilot workforce size remains stable and also the value of a dual-pilot cockpit as an avenue to build the tacit knowledge required for expert intuition.

Another point of discussion observes the legal implications of this shift to a learning function. Although the premise about pilot total control may approach its limit, it does provide clear judicial demarcations between the accountabilities of aircraft manufacturers, operators and pilots. By acknowledging the opacity and ambiguity (as a result of aircraft and operational complexity) and accepting the need for a learning function within the cockpit JCS, accountability for accidents and incidents may shift between these stakeholders. Are manufacturers responsible for creating opaque systems? Are operators and training organizations responsible for too much flexibility in procedures sensemaking approaches? Are pilots responsible for deviating from (or complying with) procedures? While Airmanship 2.0 may introduce new legal tensions, this redistribution of accountability has already begun in the aftermath of accidents such as Air France 447, Lion Air 610 and Ethiopian 302, where pilot accountability has made room for manufacturer design accountability (Schwab, 2024; Air Data News, 2025; Garcia, 2025; Charpentreau, 2025; Chokshi, 2025; Reuters, 2026). Such judicial discussions may even become a driving force to challenge the now-defunct assumption about pilot total control.

Despite the above challenges, reaching the next level of aviation safety requires a new approach to safety in response to complexity-related ambiguity and opacity: a stronger human sensemaking function may provide the requisite mitigation. Despite technology having offloaded human pilots of many functions, the human's neurocognitive assets may still be the best source of aviation safety and resilience yet. Future cockpit JCS designs can facilitate the Airmanship 2.0 concept by partially offloading human pilots from the executive and compliant end of their currently bifurcated role. This creates the requisite space for human pilots to do what they do best: explore, learn and adapt. Human brains have evolved for this specific function, how to make use of this unique capability is up to us.

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A. Appendix A: Considerations for Training Airmanship 2.0

A.1. Pilot Selection

Existing commercial pilot selection programs are generally quite skill-oriented, with a focus on basic psychological testing, handling skills and increasingly basic socialization skills being assessed. More advanced selection programs feature a competency-based approach, which tends to be a better predictor of pilot suitability (González Cabeza et al., 2021). Some air force selection programs have even reduced this to selecting solely on intelligence, personality and medical checks, as evidence shows that these are the most relevant predictors for trainability in military flight (Caretta et al., 2014). In a similar vein, how could selection programs enrich themselves further with useable indicators for problem-solving, mindfulness and emotional maturity? A possible improvement could be by cross-referencing metrics such as intelligence (a basic prerequisite), evaluation of behavioral markers in role playing exercises and interviews that explore a candidate's meta-cognitive awareness (e.g., self-awareness, tolerance for ambiguity, cognitive flexibility).

A.2. Ab-initio Training & MCC

While initial selection may only filter out those candidates which have a poor disposition from the onset, selected candidates are by no means competent in the cognitive abilities required. Furthermore, skills such as emotional regulation and mindfulness can take months or even years to manifest effectively in a person. Therefore, ab-initio training may be the best moment to begin developing these abilities. For example, mindfulness training adapted to the flight training context could be a valuable extension of the ground school program. Abilities such as non-judgmental awareness and startle recovery are so universal that they could even be developed prior to any flight training, with benefits for a candidate's general well-being to boot. Such training objectives could merge well with the shift to ab-initio CBTA programs such as the MPL program. For example, in the Multi-Crew Coordination (MCC) training program, case-based exercises could be used to reinforce CRM collaboration skills with shared awareness and analytical sensemaking techniques. Also consider the value of developing emotional maturity to boost crew coordination training in the MCC phase.

A.3. Type Rating & ZFTT

The (initial) type rating is often the first time a candidate experiences the system and operational complexity requiring the new emotional and sensemaking abilities described in this article. This training phase provides an invaluable opportunity to connect these already trained and internalized abilities with the operational context that requires them. The technical and procedural nature of most type rating programs would have to make room for sensemaking cases which present the candidate with a situation that is *experienced* as ambiguous and opaque. Guided practice to apply these (meta-)cognitive abilities allows trainees to experience how these approaches structure their resolution of these cases. Better yet, consider that purposely presenting such cases before the candidate has internalized all the aircraft-specific knowledge and procedure training would more readily present an opaque situation (due to artificial lack of knowledge) and stimulate creative action.

More advanced problem-solving cases should also be provided near the end of the type rating or in the Zero Flight Time Training (ZFTT) phase (possibly as additional ground training) to allow the candidate to connect these problem-solving abilities with a complete knowledge of the aircraft and its procedures. Similar to other training phases in the regimen, CBTA type ratings (currently on the rise, with major OEM's developing them for their aircraft models) will mesh well with the non-technical nature of these (meta-) cognitive abilities.

A.4. Recurrent Training

Recurrent training has seen several marked developments and extensions in recent years which connect well with the (meta-)cognitive skill training, such as EBT. The CBTA competency frameworks can be readily expanded with additional competencies or observable behaviors (OB's) to encompass these (meta-)cognitive abilities as training objectives. Furthermore, the Line Oriented Flight Training (LOFT) based scenarios in such CBTA programs are also effective contexts to allow crews to experience a situation which develops in ambiguity and opacity. Refreshing practical startle and surprise recovery training (e.g., two-yearly) would also reinforce these skills without being very explicit about them, and CRM ground training can also feature exercises to practice collaborating in analytical and intuitive problem solving. A more radical proposal could be to extend the annual medical check with a mental-wellbeing check. This requires a significant shift towards establishing a safe environment for pilots to be honest about their mental health. A possible approach would be to shift from a mental "check" to mental coaching/training, to determine what type of support a pilot needs to improve his/her mental health (e.g., improve factors such as health, family, stressors, financial pressure).

A.5. Command Upgrade Training

Command training already focuses on specific competencies such as leadership, teamwork and decision making. However, given the differentiation between novice and expert problem-solving strategies (analytical and intuitive, respectively), command training could be augmented to extend a candidate's problem-solving skillset with intuitive thinking and attention switching (increasing the ACC's activity). Such training could consist of advanced mindfulness training that address the reduction of self-doubt, which maintaining attention switching abilities and increased sensitivity to one's intuition. Furthermore, the command training should also ensure that crew captains are able to stimulate and facilitate an atmosphere conducive to healthy cognitive functioning and effective crew problem solving dynamics.

A.6. Instructor Training

Instructor qualifications and training have also improved significantly with the introduction of CBTA and EBT training programs. In particular, the Instructor & Examiner Competency (IEC) framework shared by ICAO, EASA and IATA (ICAO, 2023) is a good example where special emphasis has been placed on interpersonal skills, ability to facilitate and to manage a healthy learning environment. As such, instructors can be particularly useful to reinforce the Airmanship 2.0 (meta-)cognitive by facilitating self-reflection, and challenging crews at the appropriate level by understanding how opacity and ambiguity can be tuned to challenge the crews learning abilities. At a minimum, instructors should be competent in both analytical and intuitive problem-solving approaches, and may even have to put them to use to be able to develop a trainee's abilities with specific meditation exercises, *Socratic questioning* and personal interviews. This may restrict relatively young first officers to function as (type-rating) instructors.

A.7. Examiner Training

The examiner is a key agent to assure the quality of flight crews throughout all training phases. Where CBTA assessments are a challenge for today's instructors, assessing a candidate's mindfulness ability or intuition will be even more difficult as their abilities will not always feature clear external behavioral markers. Similar to instructors, examiners must be expert facilitators such that both the examiner and the candidate can discover the candidate's cognitive activities and assess if they are up to standard. In most cases, an examiner will have gained sufficient experience as an instructor to develop the necessary facilitation skills.

Many suggested training interventions described in this section are unconventional when compared to the task- and procedure-centered training that constitutes the mainstay of today's aviation training and checking. There is no doubt that these changes will create uncomfortable, confrontational experiences and encounter resistance and skepticism. However, experience in training and introducing CBTA and EBT within the industry has shown that – when framed appropriately – such changes are seen as a welcome, refreshing change to the monotony and compliance it (partially) replaces. While EBT and CBTA are still relatively close to the operational context, the introduction of startle training, metacognition, mindfulness and higher order neurocognitive and self-reflective exercises will require trainees and trainers to explore training that is less operationally specific and much more personal in nature.