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The Triad of Situational Awareness Framework: A Systematic Approach to Managing Threats and Errors in Aviation

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Abstract

Threat and Error Management (TEM) is a foundational concept in aviation safety, emphasizing proactive identification and mitigation of operational threats and human errors. Central to effective TEM is situational awareness (SA), which enables pilots to perceive, comprehend, and project critical information in dynamic flight environments. Despite extensive research on SA, gaps remain in categorizing the specific types of awareness necessary for comprehensive threat and error management. This study introduces the Triad of Situational Awareness Framework (TSAF), which categorizes situational awareness into three interrelated dimensions: self-awareness, system awareness, and environmental awareness. Using a qualitative Comparative Case Analysis approach, the study examines the crashes of Colgan Air Flight 3407 and Trans-Colorado Flight 2286 to explore how breakdowns in these dimensions contributed to accidents. Findings indicate that lapses in any TSAF dimension can cascade into complete situational awareness failure, compromising a pilot's ability to recognize threats and mitigate errors. Self-awareness deficits, including fatigue and impaired proficiency, system awareness lapses such as delayed instrument monitoring, and environmental awareness failures, including misperception of weather or terrain, were all critical factors. The study demonstrates that integrating TSAF into pilot training and operational practices can enhance threat and error management, improve decision-making, and reduce the risk of aviation accidents

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Threat and Error Management (TEM) is an overarching safety concept that grew out of the evolution of Crew Resource Management (CRM) with the goal of improving both aviation operations and human performance (Maurino & Seminar, 2005). At its core, TEM provides a proactive framework for understanding and addressing the realities of everyday flight operations, where pilots constantly interact with dynamic environments, complex systems, and diverse human factors (Maurino & Seminar, 2005).

The concept emphasizes two primary tasks. First, it involves identifying and managing *threats*, which are factors or conditions that can disrupt normal operations (Maurino & Seminar, 2005). These include environmental conditions such as adverse weather, operational challenges such as tight schedules or air traffic congestion, and organizational factors such as inadequate resources or procedural shortcomings (Maurino & Seminar, 2005). Threats do not automatically lead to accidents, but they increase operational complexity, reduce safety margins, and require pilots to recognize and respond appropriately (Maurino & Seminar, 2005).

Second, TEM focuses on *mitigating errors*, which are the direct or indirect consequences of human actions or inactions that deviate from intended plans, established procedures, or required standards (Maurino & Seminar, 2005). They may result from miscommunication, incorrect decision-making, loss of situational awareness, or skill-based slips and lapses. Left unaddressed, errors can compound into undesired aircraft states or accidents. Thus, error management is not about eliminating human fallibility, but about developing strategies and resilience to contain errors before they escalate (Maurino & Seminar, 2005).

A central factor in the success of TEM is situational awareness. Situational awareness is a critical factor in flight safety, often described as a mental model of one's environment (Lawrenson et al., 2023). It has also been defined as the cognizance of entities in the environment, understanding of their meaning, and the projection of their status in near future (Munir et al, 2022).

Stanton et al. (2001) identified poor situational awareness (SA) as the primary causal factor in a review of approximately 200 aviation accidents, highlighting its critical role in flight safety. Similarly, research has shown that SA deficiencies are a leading contributor to military aviation mishaps, with approximately 85 percent of accident and incident reports attributing errors to a loss of SA (Hartel, et al., 1989), These findings underscore the importance of maintaining optimal situational awareness to enhance decision-making, reduce human error, and improve overall flight safety**.**

Given the critical role of situational awareness (SA) in flight safety, interest in this area has grown significantly among researchers, aviation professionals, and safety analysts (Idowu et al., 2022). Human factors researcher Dr. Mica Endsley developed a widely recognized model of SA, identifying three key levels: perception of environmental elements, comprehension of their meaning in the current context, and projection of their future impact (Endsley, 1999). This model provides a structured approach to understanding how pilots process information, make decisions, and anticipate potential hazards, reinforcing the need for effective SA training and assessment in aviation (Endsley, 1999).

While various definitions and levels of situational awareness highlight the importance of perceiving environmental factors, comprehending their meaning, and projecting their potential impact, they often generalize the specific dimensions of awareness that must be maintained. This is where the Triad of Situational Awareness Framework (TSAF) becomes essential. TSAF identifies three critical categories of awareness that pilots must actively sustain during flight operations in order to effectively manage threats and mitigate errors. These categories are classified as:

1. **Self-Awareness** – Encompasses the perception of one's own mental, physical, and cognitive states, including fatigue, stress, health, personal flight limitations, and operating knowledge, all of which are essential for ensuring optimal flight performance.

2. **System Awareness** – Focuses on the perception and understanding of aircraft performance, automation, avionics, and system health, enabling pilots to detect and respond to malfunctions before they become critical

3. **Environmental Awareness –** Involves the perception of external factors such as weather, air traffic, terrain, and airspace restrictions, which can significantly impact flight operations.

TSAF provides a holistic understanding of situational awareness by breaking it down into three interconnected dimensions. It also supports proactive threat and error management, thereby enhancing pilot training and performance, reducing human error, improving decision-making, and strengthening aviation safety culture.

Purpose Statement

The purpose of this paper is to establish the Triad of Situational Awareness (TSAF) as a framework for categorizing the different types of awareness that must be maintained to effectively manage threats and errors in flight operations. Situational awareness is critical to flight safety, as its breakdown has been a significant contributing factor in numerous aviation accidents and incidents (Idowu et al., 2022). This highlights the need for a structured approach to identifying and maintaining the types of awareness necessary for safe flight operations. Using Colgan Air Flight 3407 and Trans-Colorado Flight 2286 as case studies, this paper demonstrates how the proposed framework provides a practical and holistic method for recognizing and managing situational awareness, ultimately enhancing safety, mitigating risks, and improving overall flight performance.

Research Questions

- What impact do breakdowns in the Triad of Situational Awareness Framework have on flight safety?
- How can the Triad of Situational Awareness Framework be applied to enhance threat and error management in aviation?

Literature Review

Situational awareness is a vital component of flight safety, with research indicating that a loss of situational awareness contributes to 80-85 percent of aviation accidents (Idowu et al., 2022). It is also a crucial element of crew resource management (CRM), which is defined as the effective use of all available resources to enhance safe and efficient flight operations (Lawrenson et al., 2023). Over time, CRM has evolved into threat and error management, with situational awareness now being part of the central focus (Helmreich et al., 2010). Initially, CRM, when it was called cockpit resource management, aimed to address deficiencies in individual behavior, such as a lack of assertiveness among junior crew members and authoritarian leadership by captains (Idowu et al., 2024). It later evolved into crew resource management, shifting the focus to group decision-making. Today, situational awareness remains central to CRM, playing an essential role in enhancing human performance and maintaining safety in aviation operations (Lawrenson et al., 2023).

Effective situational awareness enhances workload management, as both are essential in managing threats and mitigating errors (Idowu et al., 2022). Wickens (2002) described a set of interrelated cognitive phenomena concerning awareness, aircraft control, mental resources, and strategic task management. Idowu et al. (2022) further established the relationship between workload management and situational awareness, demonstrating that maintaining situational awareness is closely tied to effective workload management. Ineffective workload management can impair the ability to perceive critical factors that affect flight operations (Idowu et al., 2022). Additionally, poor communication can pose a threat to both flight safety and situational awareness (Idowu et al., 2022). Idowu et al. (2022) also revealed that stress, fatigue, and inadequate workload management can negatively affect situational awareness.

The ultimate goal of Situational Awareness, Threat and Error Management (TEM), and Crew Resource Management (CRM) is to enhance safety (Maurino et al., 2005, Hartel et al., 1989). As shown in Figure 1, the TEM model depicts safe operations at the top, representing the desired operating environment. When a flight crew encounters operational threats or commits human errors, there is a tendency to drift away from this safe zone toward Undesired Aircraft States (UAS), defined as deviations in aircraft position, speed, or configuration caused by the flight crew (Maurino et al., 2005). These deviations may include improper use of flight controls, incorrect system configurations, failure to follow standard operating procedures, or compromised flight parameters (Maurino et al., 2005). Such deviations reduce the safety margin and are often the result of mismanaged threats, uncorrected errors, or lapses in situational awareness (Maurino et al., 2005).

However, the effective application of CRM, TEM, and situational awareness skills can help reverse this divergent trend. A key component of CRM is the development of shared mental models, a common understanding among crew members regarding the current situation, flight plan, roles, and expectations (Kanki et al., 2019). These shared mental models improve coordination, promote proactive communication, and enable crews to anticipate each other's actions, which is especially critical during high workload or abnormal situations (Kanki et al., 2019). In this way, shared mental models contribute directly to managing threats and mitigating errors by aligning the crew's perception and response to dynamic flight conditions (Kanki et al., 2019).

Figure 1: Threat and Error Management Model (Adapted from United Airlines)

As the concept of situational awareness gained popularity in the 1980s and 1990s, Dr. Mica Endsley argued that situational awareness is developed, sustained, and lost across three distinct levels: (1) the perception of critical factors in the environment, (2) understanding the significance of those factors, and (3) projecting what will happen in the near future (Lawrenson et al., 2023). These three levels of situational awareness have become a fundamental framework for understanding the concept (Endsley, 1999). Stanton et al. (2001) also supported Dr. Endsley's classification, agreeing that awareness increases as information is processed at higher levels.

Apart from Endsley’s framework of situational awareness, other frameworks have been developed, such as Distributed Situational Awareness (DSA), which takes a system-oriented approach (Stanton et al., 2006). Unlike the traditional situational awareness framework, DSA examines situational awareness within a team-based context (Stanton et al., 2006). This framework asserts that situational awareness is not solely maintained by an individual but is instead distributed across the entire system, with team members collectively holding relevant knowledge to sustain awareness (Stanton et al., 2006). However, despite the significance of Endsley’s three-level situational awareness framework and the Distributed Situational Awareness framework by Stanton et al. (2006), there remains a gap in categorizing the specific types of awareness that must be maintained to effectively manage threats and mitigate errors within a structured framework.

Methodology

Research Design

This qualitative study employed a Comparative Case Analysis research design to examine the categorization of different types of awareness necessary for managing threats and errors in flight operations within the Triad of Situational Awareness Framework. Additionally, it explored how breakdowns in this framework can impact flight operations. Comparative Case Analysis is a qualitative research method used to examine and compare two or more cases in order to identify patterns, similarities, and differences (Creswell et al., 2017). This study examined and compared the crashes of Colgan Air Flight 3407 and Trans-Colorado Flight 2286 to assess how breakdowns in environmental, personal, and system awareness can impact flight performance and safety.

These accidents were selected because a loss of situational awareness played a critical role in both events. They underscore the importance of maintaining situational awareness throughout all phases of flight, as each involved a series of breakdowns in environmental, personal, and system awareness. By analyzing these cases, the study sought to provide valuable insights into the role of the Triad of Situational Awareness in enhancing flight safety. Data for this research were drawn from the National Transportation Safety Board (NTSB) database, which included detailed reports, flight data, and investigative findings—offering a comprehensive overview of these crashes and their contributing factors.

The comparative case analysis began with the selection of Colgan Air Flight 3407 and Trans-Colorado Flight 2286, chosen for their shared characteristic of situational awareness breakdowns. This was followed by an in-depth review of the NTSB investigation reports to gain familiarity with each case. Guided by existing literature on human factors in aviation, a coding schema was then developed, focusing on three key dimensions of situational awareness: Self-awareness, System awareness, and Environmental Awareness

Coding was conducted manually to systematically identify incidents and behaviors related to each dimension. Self-awareness encompassed physical and cognitive states, including fatigue, stress, health, personal flight limitations, and operational knowledge; system awareness focused on aircraft performance, automation, avionics, and system health; and environmental awareness included factors such as weather, air traffic, terrain, and airspace restrictions.

After coding, the two cases were compared to identify both common patterns and distinct differences that led to breakdowns in situational awareness. This comparison revealed how the interplay among the three categories contributed to each accident, offering insights into areas where enhanced training and safety protocols are needed. The analysis was limited by variability in data completeness across cases and by potential researcher bias, which was mitigated through peer review.

Description of the Accident- Colgan Air Flight 3407

On February 12, 2009, at approximately 2217 EST, Colgan Air Flight 3407, a Bombardier DHC-8-400 (N200WQ), crashed into a residence in Clarence Center, New York, during an instrument approach to Buffalo-Niagara International Airport. The crash resulted in the deaths of all 49 people aboard, including two pilots, two flight attendants, and 45 passengers, as well as one person on the ground (NTSB, 2010)

The flight took off and reached its cruising altitude of 16,000 feet without incident. The first officer briefed the landing airspeeds, and shortly after, the captain began the approach briefing. As they descended, the first officer noted ice accumulation on the windshield. Despite performing some flight-related duties, the crew engaged in unrelated conversations. During the flight, the cockpit voice recorder (CVR) recorded the captain making a sound similar to a yawn, indicating a sign of fatigue (NTSB, 2010).

As they approached landing, the captain instructed the crew to adjust the flaps and landing gear, but the airplane experienced a series of warnings, including the activation of the stick shaker, which indicated an impending stall. The flight data recorder (FDR) data showed that, while engine power was increasing, the airplane pitched up, rolled to the left, reaching a roll angle of 45° left wing down, and then rolled to the right. As the airplane rolled to the right through wings level, the stick pusher activated (about 2216:34), and flaps were set to 0 (NTSB, 2010).

The airplane's pitch and roll angles became dangerously unstable, and despite the crew's attempts to regain control, the aircraft ultimately crashed into the home, resulting in a postcrash fire (NTSB, 2010).

Description of the Accident- Trans-Colorado Flight 2286:

On January 19, 1988, N68TC, a Trans-Colorado Airlines aircraft operating as Continental Express Flight 2286, departed Denver International Airport (DEN), Colorado, with two flight crew members and 15 passengers en route to Durango–La Plata County Airport (DRO). The flight departed around 18:20 and climbed to its assigned altitude of 23,000 feet MSL, then leveled off. The captain was acting as the pilot monitoring, while the first officer was the pilot flying (NTSB 1989).

Shortly after departure, Denver ARTCC asked Trans-Colorado if they preferred the ILS (Instrument Landing System) or VOR-DME approach to Runway 20. The captain responded that they would plan for the VOR-DME approach. Denver ARTCC then advised, "If you want to proceed direct to the DRO zero-two-three radial, 11-mile fix, that is approved." The captain acknowledged this instruction (NTSB 1989).

Later, Denver ARTCC cleared the flight to descend at the pilot's discretion to 16,000 feet MSL, which the captain acknowledged. Shortly afterward, they were cleared to 15,000 feet, and the captain again acknowledged the clearance. Three minutes and 28 seconds later, Denver ARTCC instructed the flight to cross the DRO 023 radial, 11-mile fix, at or above 14,000 feet for the VOR-DME Runway 20 approach to DRO. The captain did not respond immediately, prompting the controller to repeat the clearance. The captain then confirmed, stating they were descending to 14,000 feet MSL and were cleared for the approach (NTSB 1989).

At 19:16:15, Denver ARTCC informed the flight that radar coverage was terminated. Shortly after, the crew announced they were beginning their initial descent to DRO and instructed passengers to fasten their seatbelts. The airplane later leveled off briefly, then experienced a hard impact followed by an abrupt pitch-up and an increase in engine power. The aircraft rolled several times laterally before striking the ground and coming to rest approximately five miles from the airport (NTSB 1989).

Research Design Conclusion

The case study methodology provides a structured way to evaluate the TSAF's applicability in real-world flight operations. By analyzing past incidents, this study demonstrates how maintaining **balanced situational awareness across the three categories** can enhance pilot decision-making and mitigate aviation risks.

Results

The analysis of the crashes of Colgan Air Flight 3407 and **Trans-Colorado Flight 2286** revealed critical breakdowns in all three components of the Triad of Situational Awareness (TSA): environmental awareness, personal awareness, and system awareness. The findings highlight how deficiencies in each category contributed to the accident and demonstrate that a more structured approach to situational awareness could have mitigated the risks.

1. **Breakdown in Self-Awareness**

Breakdowns in self-awareness were evident in both events. In the case of Colgan Air Flight 3407, the investigation revealed that both the captain and first officer exhibited signs of fatigue due to insufficient rest prior to the flight (NTSB 2010). This likely contributed to diminished situational awareness and poor decision-making. Furthermore, a knowledge-related error played a major role. According to the NTSB, the inappropriate response to the stick shaker activation resulted from inadequate operating knowledge, which was identified as the primary cause of the crash (NTSB, 2010).

Similarly, in the crash of Trans-Colorado Flight 2286, the investigation determined that the captain had used cocaine prior to the flight, rendering him medically unqualified to serve as a flight crew member (NTSB 1989). This impairment significantly affected his perceptual skills and overall abilities at the time of the accident. The effects of cocaine, such as withdrawal symptoms, significant mood alterations, intense drug cravings, and post-cocaine-induced fatigue, could each, individually or in combination, have degraded his ability to fly and monitor the first officer's performance during the flight according to the investigation (NTSB 1989).

Additionally, the first officer's inadequate knowledge of instrument flying was determined to be another contributing factor. His prior flight history revealed deficiencies in instrument procedures, and his decision to descend below published minimums reflected these shortcomings in instrument flying proficiency (NTSB 1989).

2. **Breakdown in System Awareness**

As highlighted in the investigation of Colgan Air Flight 3407, the flight crew failed to perceive the decreasing airspeed until the stick shaker activated, signaling an impending stall (NTSB, 2010). This delay in recognizing the deteriorating flight condition reflects a breakdown in system awareness, evidenced by delayed and inadequate instrument scanning (NTSB, 2010). Similarly, in Trans-Colorado Flight 2286, the crew demonstrated a loss of system awareness by failing to maintain a mental model of the approach's progression, ultimately preventing them from recognizing the impending danger of terrain proximity (NTSB 1989).

3. **Breakdown in Environmental Awareness**

In both Colgan Air Flight 3407 and Trans-Colorado Flight 2286, lapses in environmental awareness were key contributors to the accidents. For Flight 3407, icing conditions degraded the aircraft's aerodynamic performance, and despite activating the anti-ice system, the crew failed to anticipate its impact on flight configuration during approach (NTSB, 2010). Similarly, Flight 2286's crew lacked awareness of terrain proximity during the approach phase, directly compromising flight safety (NTSB 1989). In both cases, the failure to accurately perceive and respond to critical environmental factors played a central role in the accidents.

Summary of Findings

The analysis of the Colgan Air Flight 3407 and Trans-Colorado Flight 2286 accidents reveals significant breakdowns across all three dimensions of awareness: self-awareness, system awareness, and environmental awareness, as summarized in the table below. These cases underscore the critical need for enhanced pilot training focused on recognizing and maintaining these dimensions of awareness to improve overall flight safety.

Table 1

Summary of Breakdowns in Self-Awareness, System Awareness, and Environmental Awareness in the Colgan Air Flight 3407 and Trans-Colorado Flight 2286 Crashes

Dimensions of Situational Awareness	**Colgan Air Flight 3407**	**Trans-Colorado Flight 2286**
Self-Awareness	• Fatigue • *knowledge-related* error	• First officer's inadequate knowledge of instrument flying • Captain medically unqualified due to cocaine use.
Environmental Awareness	• Weather	• Terrain
System Awareness	• Delayed in instrument scanning	• Loss of the mental model of the approach's progression.

Discussion

The results of the comparative analysis of Colgan Air Flight 3407 and Trans-Colorado Flight 2286 revealed that breakdowns in any of the three dimensions of awareness: self, system, and environment, can create the conditions for a complete loss of situational awareness. Such breakdowns compromise a pilot's ability to effectively perceive, comprehend, and project critical information, thereby reducing their capacity to recognize emerging threats or mitigate errors. If proper and timely corrective action is not taken, these lapses can escalate rapidly, ultimately leading to unsafe flight conditions and, as demonstrated in these accidents, catastrophic outcomes. As shown in Figure 2 below, these dimensions of awareness are interconnected, and a breakdown in one dimension can affect the others.

Figure 2: The Triad of Situational Awareness Framework

Self-Awareness

Self-awareness involves recognizing one's own mental, physical, and cognitive states, including fatigue, stress, health, personal flight limitations, and operating knowledge. These internal conditions directly affect decision-making and performance in the cockpit (Guastello, 2014). When a pilot fails to recognize or mitigate impairments in these areas, it sets off a chain reaction that can erode situational awareness and increase vulnerability to errors.

One of the most insidious threats to self-awareness is fatigue (Guastello, 2014). Unlike a mechanical malfunction, fatigue often develops gradually, making it difficult for pilots to recognize its impact on their performance (Guastello, 2014). For example, fatigue can lead to slower reaction times, impaired memory, and reduced ability to process changing environmental cues (Guastello, 2014). The investigation into the crash of Colgan Air Flight 3407 underscored this reality. Evidence suggested that both pilots were likely fatigued, and their impaired performance contributed to the stall and subsequent crash (NTSB, 2010). Research further indicates that fatigue may have been an underlying factor in many of the approximately 23,800 general aviation (GA) accidents analyzed, even when not formally documented as a probable cause (Keller et al., 2019). Supporting this, the NTSB found that nearly 20 percent of the 182 major accident investigations between 2001 and 2012 cited fatigue as a probable cause, contributing factor, or significant finding (NTSB, 2016).

However, self-awareness is not limited to recognizing fatigue. It also encompasses awareness of personal limitations and operating knowledge (Guastello, 2014). The crash of Trans-Colorado Flight 2286 illustrates how neglect in this area can have fatal consequences. The captain, serving as pilot monitoring, was under the influence of cocaine and failed to fulfill critical responsibilities, such as monitoring the approach profile (NTSB, 1989). At the same time, the investigation revealed that the first officer lacked proficiency in instrument flying, which contributed to the aircraft's descent below published minimums on a non-precision approach (NTSB, 1989). This case highlights two dimensions of impaired self-awareness: physiological impairment in the captain and insufficient knowledge in the first officer. Both deficiencies compounded one another, ultimately leading to the crash (NTSB, 1989).

Ultimately, self-awareness is the bedrock of situational awareness. A lapse in self-awareness often cascades into failures in system awareness and environmental awareness. Once this erosion begins, the likelihood of a complete breakdown in situational awareness increases dramatically. Pilots who remain vigilant about their physiological state, cognitive readiness, and proficiency are far better positioned to interpret system cues accurately, respond effectively to environmental changes, and maintain safety margins (Guastello, 2014).

In aviation, significant emphasis is placed on advanced technologies, system redundancies, and external regulations to enhance safety (Kanki et al., 2019). However, no level of automation or oversight can fully compensate for a pilot who is unaware of their own limitations (Kanki et al., 2019). For this reason, cultivating self-awareness is not only a personal responsibility but also a vital element of aviation safety culture (Kanki et al., 2019). Flight training programs, recurrent training, and safety management systems must continue to prioritize education on fatigue, stress management, and personal minimums, ensuring that pilots maintain the foundation upon which all other dimensions of situational awareness are built.

System Awareness

System Awareness is a critical dimension of situational awareness, as it involves the perception, comprehension, and projection of an aircraft's performance, automation, avionics, and overall system health (Kanki et al., 2019). It enables pilots to detect, diagnose, and respond to malfunctions or anomalies before they escalate into safety-critical events (Endsley 2018). Modern aircraft are equipped with increasingly sophisticated systems designed to reduce workload and enhance safety (Kanki et al., 2019). However, when pilots lack a thorough understanding of how these systems function or when they fail to scan and interpret the cues provided, situational awareness can quickly deteriorate (FAA, 2011).

An essential part of system awareness is staying ahead of the airplane by actively monitoring flight instruments and understanding what the data implies for both the current and future state of the aircraft (Endsley 2018). Failure in this regard often results in reactive rather than proactive decision-making (Endsley 2018). The crash of Colgan Air Flight 3407 underscores this point (NTSB 2010). The flight crew failed to perceive the steadily decreasing airspeed until the stick shaker activated, warning of an imminent stall (NTSB, 2010). By the time the warning system engaged, recovery options were limited, and the flight crew's situational awareness had already collapsed (NTSB, 2010). This case illustrates how lapses in system awareness not only delay recognition of deteriorating conditions but also narrow the margin for corrective action.

Proper system awareness extends beyond monitoring a single instrument (Endsley 2018). It requires integrating information from multiple sources—airspeed, altitude, engine performance indicators, fuel systems, automation modes, and warning annunciators—and making sense of their collective implications (Endsley 2018). A pilot who notices an abnormal engine vibration, for example, must connect this observation to fuel flow readings, oil pressure gauges, and aircraft performance changes to diagnose whether the issue is a sensor error, a temporary anomaly, or a developing mechanical failure (FAA, 2009). Without this integrative perspective, pilots may misinterpret or dismiss system cues, increasing the risk of inappropriate or delayed responses (Endsley, 2018).

Another important aspect of system awareness is understanding the design and limitations of automation (FAA, 2009). While automation reduces workload, it can also create a false sense of security if pilots rely on it blindly without monitoring its performance (Endsley 2018). Automation mode confusion, incorrect autopilot inputs, or mismanagement of flight management systems have been implicated in multiple accidents and incidents (Kanki et al., 2019). Effective system awareness requires pilots to maintain a mental model of what the automation is doing, why it is doing it, and what it will do next (Endsley 2018). In essence, pilots must not only monitor the systems but also remain mentally engaged, questioning whether the aircraft's behavior aligns with expectations (Endsley 2018).

Consistent, disciplined monitoring of aircraft systems is therefore fundamental to safe operations (Endsley 2018). Strong system awareness enables pilots to anticipate problems, evaluate the potential consequences of anomalies, and implement timely corrective actions before hazards escalate (Kanki et al., 2019). Conversely, lapses in system awareness can trigger a cascade of errors that compromise both safety and performance (Endsley 2018). For this reason, flight training programs and recurrent checks emphasize systematic instrument scanning, system knowledge, and automation management skills as indispensable components of maintaining situational awareness.

Environmental Awareness

Environmental awareness refers to a pilot's ability to perceive, interpret, and anticipate external factors such as weather, terrain, surrounding traffic, and airspace restrictions (FAA 2009). These elements can shift rapidly and often pose significant risks if not continuously monitored and evaluated (FAA 2009). Effective environmental awareness requires not only recognizing present conditions but also projecting how those conditions may evolve and influence flight operations (Kanki et al., 2019). Pilots who maintain strong environmental awareness are better equipped to make proactive adjustments that preserve both safety and efficiency. (Kanki et al., 2019)

The crash of Colgan Air Flight 3407 provides a compelling case study of how lapses in environmental awareness can contribute to a breakdown in flight safety. Weather was the critical environmental factor in this accident (NTSB 2010). During the approach to Buffalo Niagara International Airport, the aircraft encountered icing conditions, a well-known hazard that can substantially degrade aerodynamic performance by reducing lift and increasing drag (NTSB 2010). Although the flight crew activated the aircraft's anti-ice system, they noted visible ice accumulation on the wings (NTSB 2010). However, they failed to anticipate the progressive impact of the icing on the aircraft's handling characteristics. This lack of forward-looking assessment hindered their ability to properly configure and control the airplane during the approach phase (NTSB, 2010).

This case illustrates a fundamental principle of environmental awareness: it is not enough to simply detect external hazards as they occur, pilots must also project how those hazards will develop over time and plan accordingly. In the Colgan Air accident, the crew's inability to anticipate the worsening aerodynamic consequences of ice accumulation left them unprepared for the stall that ultimately led to the crash (NTSB 2010)

Beyond weather, other environmental factors, such as unexpected air traffic conflicts, changes in terrain awareness during low-visibility operations, or last-minute alterations in airspace restrictions, can similarly challenge a pilot's ability to maintain safe operations (Kanki et al., 2019). When environmental awareness is lacking, situational awareness as a whole becomes compromised, increasing the likelihood of errors in judgment and control (Kanki et al., 2019).

Ultimately, the Colgan Air tragedy highlights the critical role environmental awareness plays in aviation safety. By training pilots not only to recognize hazards but also to anticipate their future implications, the industry can strengthen resilience against external threats and reduce the risk of accidents caused by lapses in situational awareness.

Implications for Training and Operational Practices

Integrating the Triad of Situational Awareness Framework (TSAF) into pilot training and operational practice provides a structured approach to teaching situational awareness while reinforcing Threat and Error Management (TEM). TSAF builds on the broader concept of Situational Awareness (SA), which emphasizes the pilot's ability to perceive, comprehend, and project critical information in the operational environment (Endsley 1999). By organizing awareness into three dimensions, self-awareness, system awareness, and environmental awareness, TSAF strengthens SA and provides a clear framework for maintaining it. As a result, pilots are better equipped to recognize emerging threats, anticipate potential hazards, and implement proactive measures to mitigate errors, ultimately enhancing TEM and overall flight safety. See figure 3.

For example, while the concept of self-awareness is not new in aviation, emphasizing its direct impact on situational awareness and TEM reinforces its critical role in flight safety. Pilots with strong self-awareness can recognize when they are not at peak performance or lack sufficient proficiency for a task. This recognition allows them to take appropriate corrective actions, such as resting before a flight, managing workload effectively, pursuing additional training, or seeking assistance when necessary.

Similarly, system awareness equips pilots with the ability to monitor and interpret aircraft systems, automation, and procedures, ensuring that they can detect anomalies early and respond appropriately. Meanwhile, environmental awareness enables pilots to evaluate external factors—such as weather, terrain, and air traffic—that directly influence operational decisions and safety outcomes.

By linking these three dimensions of awareness to situational awareness and TEM, TSAF helps create a stronger safety culture. Pilots begin to view awareness not as an abstract concept, but as a practical tool that directly shapes decision-making and operational performance. This integration fosters a mindset of continuous vigilance and proactive safety management, ultimately enhancing flight safety across all levels of operation.

Figure 3: The Relationship between TSAF, SA, and TEM

Conclusion

Managing threats and errors begins with the ability to recognize potential risks and accurately understand their implications for flight safety. This proactive recognition is the foundation of effective Threat and Error Management (TEM), which seeks to anticipate, mitigate, and recover from hazards before they escalate into incidents or accidents. In this context, the Triad of Situational Awareness Framework (TSAF) becomes an essential tool.

Self-awareness, system awareness, and environmental awareness form the foundation of situational awareness and effective threat and error management. By understanding these three dimensions and deliberately incorporating them into flight planning and operations, pilots are better equipped to anticipate potential threats, recognize early signs of error, and take timely corrective actions that preserve safety. Together, these dimensions provide a structured approach to monitoring the internal state of the aircraft, the external operating environment, and the human element of pilot performance.

The consequences of failing to maintain situational awareness across these dimensions are evident in major accidents. In the crash of Colgan Air Flight 3407, lapses in self-awareness (fatigue), system awareness (failure to monitor airspeed trends) and environmental awareness (underestimating the impact of icing conditions) contributed to the crew's inability to manage the deteriorating flight situation. Similarly, the crash of Trans-Colorado Flight 2286 demonstrated a breakdown in self-awareness, as fatigue and impaired decision-making undermined the pilots' capacity to respond effectively to changing flight conditions. In both cases, the erosion of situational awareness in one dimension cascaded into a complete breakdown of overall situational awareness, leaving the crews unable to recognize threats in real time or mitigate errors through proper and timely action.

These accidents highlight a critical principle: situational awareness is not static but dynamic (Stanton et al., 2001). Pilots must actively sustain and update awareness across all three dimensions of the TSAF to stay ahead of the aircraft and the operational environment. Neglecting any single dimension of awareness erodes overall situational awareness, leaving pilots more vulnerable to errors and reducing their ability to anticipate and manage threats effectively.

Ultimately, integrating the TSAF into pilot training and operational practice provides a clear pathway to strengthening TEM. By reinforcing these dimensions of awareness, the framework equips pilots with the cognitive and practical tools needed to anticipate hazards, recognize errors early, and prevent them from escalating into accidents.

References

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.

Endsley, M. R. (1999). Situation awareness in aviation systems. *Handbook of aviation human factors*, *11*, 257-276.

Endsley, M. R. (2018). Automation and situation awareness. In *Automation and human performance* (pp. 163-181). CRC Press.

Federal Aviation Administration. (2009). *Pilot's handbook of aeronautical knowledge*. Skyhorse Publishing Inc..

Federal Aviation Administration. (2011). *Instrument Flying Handbook (FAA-H-8083-15A)*. Skyhorse Publishing Inc.

Guastello, S. J. (2014). Human factors engineering and ergonomics: A systems approach (2nd ed.). Taylor & Francis Group.

Härtel, C. E. J., Smith, K. A., & Prince, C. (1989). Defining aircrew coordination: Searching mishaps for meaning.

Helmreich, R., Anca, J., & Kanki, B. G. (2010). The future of CRM. In *Crew resource management* (pp. 493-500). Academic Press.

Idowu, A., & Shogbonyo, M. (2022). Situational awareness and workload management in aviation: a case analysis of the crash of American Airlines Flight 965. *International Journal of Aviation Research*, *14*(1).

Idowu, A., Shogbonyo, M. A., Augustine, H., & Adeyeye, O. A. (2024). Evaluating Crew Resource Management (CRM) and Single-Pilot Resource Management (SRM) in Aviation. *International Journal of Aviation Research*, *16*(1).

Kanki, B. G., Anca, J., & Chidester, T. R. (Eds.). (2019). *Crew resource management*. Academic Press.

Keller, J., MENDONCA MR, F. C., & Cutter, J. E. (2019). Collegiate aviation pilots: Analyses of fatigue related decision-making scenarios. *International Journal of Aviation, Aeronautics, and Aerospace*, *6*(4), 9.

Lawrenson, A., Rodrigues, C. C., Malmquist, S., Greaves, M., Braithwaite, G., & Cusick, S. K. (2023). *Commercial Aviation Safety, Seventh Edition* (7th ed.). McGraw Hill LLC.

Maurino, D., & Seminar, C. A. S. (2005, April). Threat and error management (TEM). In *Canadian Aviation Safety Seminar (CASS)* (pp. 18-20).

Munir, A., Aved, A., & Blasch, E. (2022). Situational awareness: techniques, challenges, and prospects. *AI*, *3*(1), 55-77.

National Transportation Safety Board (NTSB) (2010). Aircraft accident report, Colgan Air Flight 3407. https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR1001.pdf

National Transportation Safety Board (NTSB) (1989). Aircraft accident report, Trans-Colorado Flight 2286. https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR8901.pdf

National Transportation Safety Board (NTSB) (2016). Retrieved from https://www.ntsb.gov/Advocacy/mwl/Pages/mwl1-2016.aspx

Stanton, N. A., Chambers, P. R., & Piggott, J. (2001). Situational awareness and safety. *Safety science*, *39*(3), 189-204.

Stanton, N. A., Stewart, R., Harris, D., Houghton, R. J., Baber, C., McMaster, R., ... & Green, D. (2006). Distributed situation awareness in dynamic systems: theoretical development and application of an ergonomics methodology. *Ergonomics*, *49*(12-13), 1288-1311.

Wickens, C. D. (2002). Situation awareness and workload in aviation. *Current directions in psychological science*, *11*(4), 128-133.