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INTEGRATING EYE-TRACKING & HEAD-UP DISPLAY IN PILOT TRAINING FOR IMPROVED OPERATIONAL & ORGANISATIONAL CAPABILITIES

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Executive Summary

Head-Up Displays (HUDs) and Head-Up Guidance Systems (HGS) introduce value beyond real-time gaze tracking. When integrated with eye-tracking solutions during training, guided by instructor and pilot input, and supported by visual and instructional learning tools, these systems can build up additional safety, organisational, and operational capability drivers for aircrews, especially amidst rising demands.

Aviation is growing. With the world's commercial fleet expected to double within twenty years, forecast traffic steadily increasing, and an experienced pilot shortage looming, training systems are on the brink of unprecedented pressure. Closely coupled to this expansion are the increasing levels of technology in the industry, which create the paradoxical challenges of advancing autonomy while retaining manual control skills.

These two major factors are driving an urgent need to improve training effectiveness, especially within associated performance monitoring. National regulators and transport safety experts have recognised that poor flight path monitoring is a major contributor to aircraft accidents, incidents, and near misses, but current regulations do not address pilot monitoring skills. As aircrew monitor more complex aircraft and systems and increasingly depend on automation, efficient scanning is critically important for effective situational awareness.

HUD/HGS are becoming more prevalent in single- and multi-crew cockpits, and they have been recognised as a powerful tool for accident prevention by substantially reducing crew error and improving aircrew situational awareness (Flight Safety Foundation, 1991). However, they do present a training challenge. It is difficult for an instructor or examiner to confirm the exact nature of a pilot's scan, or even that the HUD is being used at all.

Precision eye tracking helps overcome a gap in traditional flight simulator training: understanding aircrew behaviour, decision-making, and attention levels. By making pilots' scan patterns observable and within the normal training footprint, for the first time, instructors can confirm the degree of attention being given to flight path monitoring.

The authors posit that combining eye-tracking with HUD adds value beyond reduced errors and increased situational awareness. This combination will help maximise training efficiency and effectiveness through enabling Competency- and Evidence-Based Training; supporting data-driven training programs; extracting instructors' high-value knowledge and experience; and fostering effective brief, debrief, and learning opportunities

Growth, Efficiency, and Capacity

"In one fell swoop, we have shrunken the earth."
Juan Trippe, Founder of Colonial Air Transport

Over the next twenty years, the commercial aviation industry can expect robust growth in terms of new aircraft deliveries (37,000–46,000), global passenger traffic (4.7%), overall fleet increases (3.5%), pilot demand (+790,000), and an effective doubling of commercial aircraft in service (~25,000 – 49,000) (Airbus, 2018; Boeing, 2018; FlightGlobal, 2018).

Similarly, the air cargo, business aviation, and general aviation sectors also forecast stability or steady growth for the next ten to twenty years (Boeing, 2018; JetCraft 2018; FAA 2018). From a military perspective, average individual flying hours per year are decreasing, while operational tempo remains high and crew ratios lean (i.e. 1:1 -3:1 depending on aircraft type), particularly in fast jet fleets and squadrons (Bigelow, et al, 2003; Plain, 2019). This steady growth Is expected to generate reasonable profitability and sustainability for all organisations, and increased demand for pilots and automation—all against the backdrop of the rigorous and continuously improving safety standards demanded of the aviation industry.

In line with this deeper operational and pilot demand, flight training departments are managing an unprecedented rise in training requirements. Traditionally, experience could be gained on the line, but the industry is putting very low time pilots in command of aircrafts such as B737 and A320. "The challenge is getting the 10,000-hour brain into the head of a 200-hour pilot (Gray, 2019)." Flight training increasingly needs to make up this deficit in experience. New technologies, such as eye-tracking, have the potential to assist in accelerating the trainee from novice to expert. Understanding and adopting those new technologies has challenges, including adapting training paths to maximise learning outcomes and skill retention while remaining at the required standard over time.

These growth factors in civilian and military aviation place increased stress and demands on aircrews and the wider aviation ecosystem. If not managed appropriately, operational and safety measures may suffer.

Monitoring Matters

"Monitoring the aircraft must be considered the lifeblood of safe flight operations. The flow of attention to monitoring must not stop, or the consequences may be grave."
Sumwalt, Morrison, Watson & Taube, 1997

To deliver this growth while maintaining and improving the industry's safety record, aviation must collectively address major accident, incident, and near-miss causes. Ineffective monitoring of flight path and aircraft instrumentation has long been recognised as a major contributor to aircraft accidents and incidents. A 1994 National Transportation Safety Board (NTSB) study found that ineffective monitoring and challenging was a factor in 84% of accidents between 1978 and 1990, and the NTSB subsequently recommended that the Federal Aviation Authority (FAA) train pilots to use better monitoring techniques (Sumwalt, Cross, Lessard, 2015). Similarly, a 1994 International Civil Aviation Organisation (ICAO) study found that the "crew did not monitor properly" in half of 24 Controlled Flight Into Terrain accidents, and a 2000 UK Civil Aviation Authority (CAA) paper identified nine fatal accidents where crew monitoring lapses were contributory factors (Sumwalt, et al, 1997).

Current regulations do not explicitly address pilot active monitoring skills, despite optimal scanning behaviour being an important flight performance variable (Ziv, 2016). Flight Safety Foundation (2018) and FAA (2017) provide practical guidance and general recommendations for evidence-based, data-driven training regimes that define and address operational aspects of effective pilot monitoring. Pilot gaze behaviour and scan strategies enable appropriate monitoring and understanding of flight phases and modes, and these tactics are key contributors to evidence-based training by showcasing and supporting positive pilot behaviours during technical flying scenarios (Ziv, 2016).

Visual Scanning Pitfalls

"Several studies of crew performance, incidents and accidents have identified inadequate flight crew monitoring and cross-checking as a problem for aviation safety."

Flight Safety Foundation, 2014

"Pilots tend to spend more time fixating on the instrument panel than on the outside world," particularly in complex commercial aircraft (Ziv, 2016). Significant research has been published on pilots' scan behaviour, with some key findings being:

- Experienced pilots make many fixations of relatively short durations to specific instruments.
- The most-frequented instrument is usually the attitude directional indicator (Ziv, 2016).
- When pilots need to make changes in altitude, airspeed, or heading, they change their visual scanning accordingly. For example, pilots increase the number of fixations on the altimeter when changing altitude (Ziv, 2016).
- Pilots look more to the outside world when they face heavy traffic and in final approach (Ziv, 2016).
- Automation surprises – a conflict between the behavior of the autopilot and the required path of the aircraft – led to excessive and ineffective visual searches. Ineffective visual scan contributed to failure in dealing immediately with the conflicts. (Ziv, 2016)
- In a specific example where an automation surprise was presented to pilots, less than half understood what was happening and knew how to correct the situation fast enough to avoid a mid-air collision (Dehais, et al, 2015).

Understanding pilots' gaze and scan behavior, along with their attention levels, can offer significant safety and training benefits, as well as operational value. With automation prevalent in modern cockpits, and the industry requiring increasing the numbers of pilots given growth and retirement attrition, situational awareness through effective scanning is critically important. Combining the contextual understanding that experienced and knowledgeable instructors provide with the 'diagnosis' capability of eye-tracking and scan monitoring bridges this previously absent training link.

More Heads-Up

"Remember, you fly an airplane with your head, not your hands and feet."

Bevo Howard, American aerobatic pilot and aviation businessman

More commercial aircraft manufacturers have introduced what was once exclusive to military aircraft: the Head-Up Display (HUD), also known as a Head-up Guidance System (HGS). The HUD is "a means of presenting information to the pilot in the line of their external forward vision which projects key flight instrument data onto a small 'see-through' screen positioned just in front of the pilot line of sight looking ahead out of the aircraft" (Skybrary, 2019). The intent being to provide the pilot(s) with increased situational awareness, without needing to look away from their external view. This is especially critical during the climb, descent, and approach phases of flight, where most serious incidents and accidents occur, and where critical flight path parameters of altitude and airspeed have been historically under-monitored (Sumwalt, Cross, Lessard, 2015).

Boeing's 737, 747, 777, and 787 families are available with HUDs, as are Airbus A320, A330, A340, A350, and A380 families. Bombardier, Cessna, Dassault, Embraer, and Gulfstream also offer HUDs of varying sophistication on their respective business and general aviation aircraft.

However, some key problems have also been identified with HUD usage:

- Attention capture, also known as tunneling, in which pilots can become focused on the HUD display to the exclusion of adequate reference to events or information outside the aircraft (Skybrary, 2019). Trainees are usually introduced gradually to expanded HUD information to try to avoid this information capture.
- Critical external scene information can be obscured by display imagery (Skybrary, 2019). For example, the brightness level of the HUD is critical. Experienced pilots recognize when to adjust the brightness levels downwards to avoid obscuring traffic and other visual cues.
  > As Captain Matthew Gray (2019) noted, *"Background lighting is very important. As an example, LAX at night is a sea of lights at a very bright intensity. This causes the pilot to continually adjust the lighting levels from about 2000 feet. You need to see the runway, aimpoint, traffic that is clearing the runway, and more. In the flare, if the brightness is too high, you can fixate on the symbology and miss the visual cues needed to adjust for runway surface closure. Also in strong crosswinds, the display becomes non-conformal. This is something trainees have difficulty with, so it is then critical to declutter the presentation."*

> Similarly, Wing Commander Plain (Royal Australian Air Force) remarked, *"A common error made by novices is failing to adjust HUD brightness. Frequently, the HUD is too bright, leading to aircrew concentrating on the HUD display and missing outside cues."* WGCDR Plain also noted that various air forces introduce HUD flying at different stages of ab-initio or lead-in fighter training. This shapes the comfort and proficiency with which junior aircrew use the HUD. Anecdotally, where HUDs are introduced early in training, there tends to be an overreliance on the HUD, manifesting in HUD-focus rather than looking beyond the HUD and flying the aircraft more holistically. Conversely, introducing the HUD later in training generally leads to some friction in effectively utilising the HUD in the first several sorties.

- HUD information is initially presented non-intuitively, ineffectively, or insufficiently, potentially negating the positive value of the HUD.
- The HUD is more sensitive than traditional instruments and will often show small changes that are not apparent on the Primary Flight Display (PFD). This can force inexperienced HUD pilots to overcontrol as they chase the guidance cue, which is tiring, increases workload, and reduces mental capacity. Instead of following the basic flying tenets of 'select, hold, trim,' aircrew can chase very small errors at the expense of cognitive bandwidth, and for negligible aircraft performance.
- Prior flying experience has been found to influence gaze behavior, particularly in pilots with HUD experience against pilots with no HUD experience. A 2002 study showed that HUD-experienced pilots relied mostly on the HUD, while pilots with traditional instrument experience relied mainly on the cockpit multi-function displays (Brown, Vitense, Wetzel, & Anderson, 2002). Anecdotally, this can cause inaccurate flying through small errors as inexperienced pilots try and look in two different places (HUD and PFD) and switch between two different scan styles.
- Given the utility and value of HUD information, pilots may develop a reliance on using the HUD. This can create problems if there is an issue with the HUD, or if pilots need to revert to traditional cockpit instruments and scans.

HUDs do provide value to pilots and operations, and their use is increasing throughout military, commercial, business, and general aviation. However, "the HUD is not intuitive - it requires training and continual practice," as well as guidance from experienced instructors, particularly for less experienced traditional-instrument pilots (Ercoline, 2000). With HUDs typically used for short periods during private, business, and commercial flights, it can be a challenge for pilots to reach a level of proficiency, let alone understand if they are correctly scanning or monitoring HUD information. "For military fast jet pilots, the HUD is used for most flight phases. Consequently, military fast jet aircrew normally reach and maintain solid HUD flying skill competency. The corollary is that they get 'rusty' on head-down flying skills" (Plain, 2019). The HUD is more than just the seemingly straightforward small window to display information.

HUD Monitoring

"Never let an airplane take you somewhere your brain didn't get to five minutes earlier."
Anon

Pilots and crews undertaking initial HUD training should be made aware of limitations, contingencies, and how to operate in failure and reduced modes. Deliberate awareness should be paid to attention capture, through visual scanning training between the HUD symbology and the outside world, similar to traditional selective radial scans and the external view. "The idea of looking past the HUD symbology and focussing on the visual scene should be emphasised as a way to properly include outside cues in the visual scan (Nichol, 2015)."

Effectively training and evaluating a pilot's scan while using a HUD presents additional challenges to traditional instrument monitoring, with a weakness of traditional simulator training being that there is "no specific feedback of the trainee's visual scan pattern" (Yu et al, 2014). This deficiency is even more apparent in a HUD environment where the ability for an instructor to ascertain a pilot's gaze is significantly reduced.

The use of eye-tracking technology, coupled with directed training for instructors, helps to address this limitation. It also multiplies the HUD from a one-way instrumentation and visualisation tool for the pilot, to an instructor tool that sheds insight into a pilot's cognitive processes and situational awareness, through precise gaze tracking, dwell time, and scan behaviour (van de Merwe, et al, 2010). By maximizing understanding of individual HUD use, eye-tracking technology creates organizational learning and instructional solutions during training and beyond.

For instance, HUD eye-tracking could measure and evaluate pilots' compliance with, and the effectiveness of, standard operating procedures (SOPs) Similarly, the technology could help organisations gain a better aggregate understanding of pilots' and aircrew normal, routine, safe performance; and the continuous loop between scan, cognition, control input, error correction, and back to scan; rather than specific incident and accident issues, which offers value and lessons in line with Safety-II – learning from what goes right (Eurocontrol, 2013; Wannaz, 2019). Novice pilots lack the experience, situational awareness, and mental models that experienced pilots bring in knowing what a particular sequence looks like, thereby driving a selective and efficient scan. Eye-tracking technology can directly address this training opportunity and teach better scanning techniques.

The operational and training data collected through eye-tracking translates into organisation improvements. Using it to inform and understand how pilots and crews respond to events, how they operate nominally, and how they extract information through the HUD and traditional instruments, leads to greater capability, safety, and more effective crew resource management and flying.

Aviate-Navigate-Communicate-Administrate…Integrate

"The best safety device is the pilot, who, deep down, regardless of the aircraft, retains a sense of fallibility and vulnerability. No system can ever substitute for that."

Arnold Reiner, retired airline captain and a former director of flight safety at Pan Am, Pilots on Autopilot, the New York Times, 16 December 2009

We know that there will be significantly increased levels of aircraft, pilots, air traffic, and HUD population, placing further stress and demands on the whole aviation ecosystem. This paper posits that integrating eye-tracking with head-up displays offers opportunities to optimise pilot training through:

- Enabling Competency- and Evidence-Based Training (i.e. where is the pilot / crew looking during specific events);
- Supporting data-driven training programs, continually updated, based on pilot-level performance (i.e. generating best practices, evaluating scenarios, and comparing across different experience levels and cohorts);
- Extracting the high value that experienced and knowledgeable and trained instructors hold (i.e. interpreting scenarios, context, and narrative, through instructional knowledge and experience); and,
- Enabling high-quality, efficient, and effective brief, debrief, and learning opportunities (i.e. visual and instructional tools based on current and relevant data and evidence) (Flight Safety Foundation, 2018).

Integrated eye-tracking solutions configured for single pilots, or multi-crew; for HUD and traditional instruments; introduce value beyond real-time gaze tracking. Analysing and implementing training improvements based on the data introduces more organisational and operational capability drivers. As a broader value-add, if HUDs 'flip the light switch' in terms of adding situation awareness for pilots (Dassault Aviation, 2018), understanding and improving pilots' HUD and instrument monitoring through eye-tracking illuminates situation awareness for the broader organisation and industry. Effective eye-tracking enables every simulator session to serve beyond a pilot or crew's immediate training and extend to helping organisations identify and learn from positive and negative events and behaviours. Ultimately, this will help address the growing gap between the demand and availability of experienced pilots.

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