# Visual Monitoring Behavior in Dual- and Reduced-Crew Configurations During Abnormal Events

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**Abstract** The proposed reduction in commercial flight crew sizes, together with evolving cockpit operational concepts, introduces significant human factors challenges related to attention management, workload allocation, and pilot–automation interaction. Although such scenarios may be confined to specific flight phases, they highlight the continued importance of robust cockpit monitoring and have intensified interest in digital assistants to support task execution and decision-making. This study presents a comparative assessment of eye-tracking metrics and visual scanning strategies adopted by two professional pilots operating an A320 full-flight simulator. A representative short-haul mission was performed under nominal and abnormal conditions, including a hydraulic failure, in both dual- and single-pilot configurations. Gaze data were collected using Tobii Pro Glasses 3 and analyzed through an area-of-interest–based approach to characterize scanning pattern complexity. Preliminary results indicate distinct monitoring behaviors across conditions, largely influenced by the presence and modality of assistance.

## Introduction

Visual monitoring is essential for commercial piloting, as it enables the continuous construction and maintenance of situational awareness through structured scan patterns, selective attention, and systematic cross-checking of cockpit information. [1] Persistent shortcomings

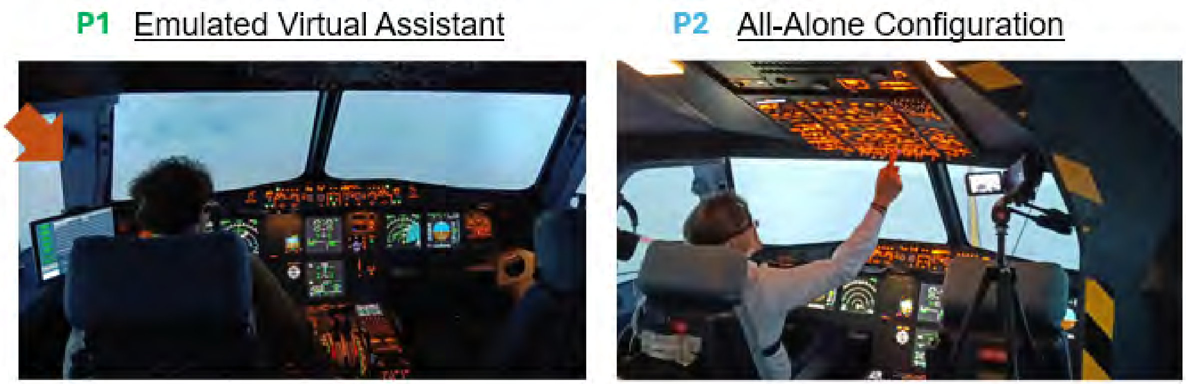



Figure 1: Single-crew configurations employed for the two pilots.

in monitoring performance, however, continue to contribute to major incidents and crew-related operational errors [2]. This is partly attributable to the vulnerability to fatigue, which can degrade scanning strategies and impair the timely detection of safety-critical events [3]. These observations extend across diverse operational domains, with eye-movement behaviour shown to reflect operators' supervisory functions and cognitive states. [4] Concerning aviation, pilots' scanpath organization varies systematically across flight phases, while different expertise levels can affect fixation distributions and visual strategy structures. [5, 6] Recent advances in eye-tracking technology [7] have enabled precise and largely unobtrusive measurement of gaze behaviour in both operational settings and high-fidelity simulation environments [8]. Consequently, these tools are now widely employed for workload assessment, training evaluation [9], and predictive modelling in human–machine interaction [10]. As flight decks progress toward higher levels of automation, the potential transition to reduced crew operations [11] is expected to redistribute attentional resources that currently benefit from cooperative scanning and shared mental models. This shift raises concerns regarding increased attentional demands on the remaining pilot, thereby motivating renewed interest in monitoring behaviours and in the potential contribution of intelligent aiding systems. Despite the valuable insights provided, the correspondence between eye movements and attention is not perfect, as attentional shifts and peripheral information processing may occur without direct fixation. Accordingly, eye-based measures are most informative when triangulated with complementary data sources.

**Experiment and Data Analysis**

An experimental campaign was conducted using an Airbus A320 FNPT II MCC simulator at KKtoFly (Collegno, Italy). Two A320 type-rated male pilots each flew the same short-haul mission from Torino Caselle (LIMF) to Rome Fiumicino (LIRF) under dual- and single-pilot configurations, with a qualified co-pilot included when required. For each configuration, two scenarios were tested: (i) a nominal baseline and (ii) a Green + Yellow (G+Y) hydraulic system low-pressure failure, requiring early landing preparation, degraded flight-envelope protections, reduced system redundancy, and predominantly manual control via ECAM-directed procedures. All missions included variable weather and standard ATC interactions, handled by a dedicated operator. As a starting point for single-pilot operations, tasks normally assigned to the co-pilot are assumed to be performed by the captain, although the target

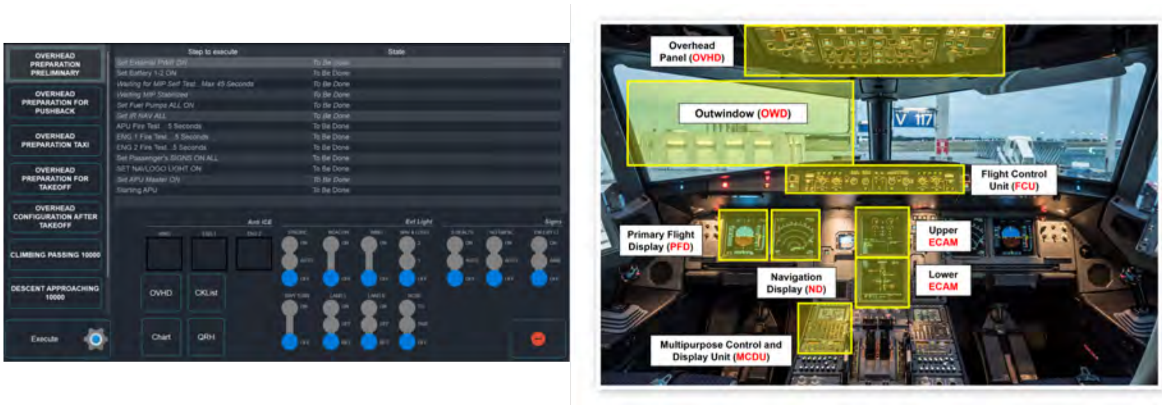


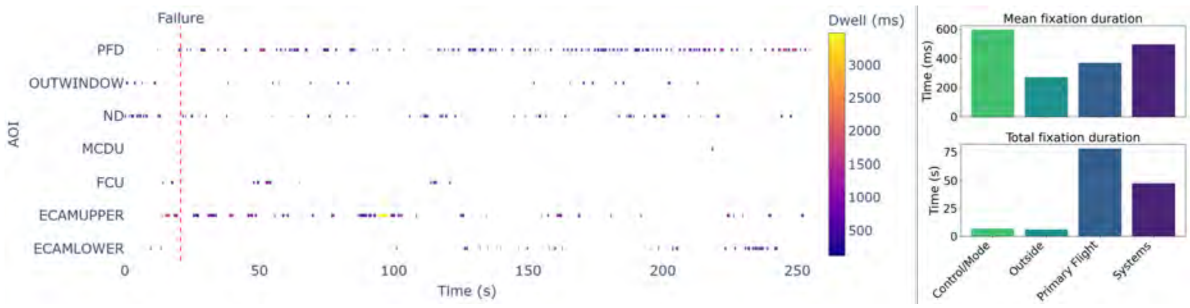

Figure 2: On the left - A sketch from the Virtual Assistant landing page. On the right - AOI definition inside the A320 cabin.

scenario involves collaboration with intelligent assistive entities. Two experimental variants were therefore implemented (see 1). The first corresponds to an unassisted "all-alone" condition, in which higher workload and monitoring demands are intentionally imposed on the pilot (Pilot #2) to stress and test his condition. By contrast, the second condition provides the pilot (Pilot #1) with a custom software tool on the Electronic Flight Bag that replicates selected overhead-panel functions, executes predefined routines (e.g., overhead configuration and ECAM procedures), and provides continuous feedback. Readers can refer to the left-hand side of 2. This assisted mode redistributes task allocation and is expected to influence monitoring strategies and eye-movement behavior.

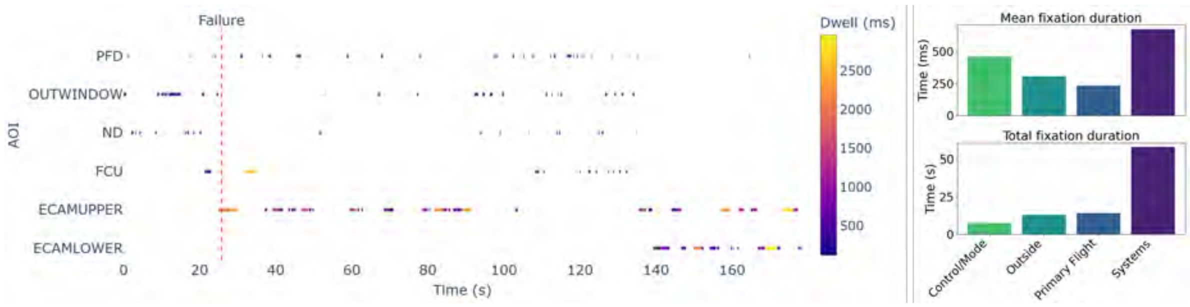
Pilot gaze was recorded using Tobii Pro Glasses 3 at 50 Hz and processed using Tobii Pro Lab software. Gaze samples were classified into fixations and saccades. In accordance with established eye-tracking standards [12], fixations were identified using a minimum duration threshold of 120 ms. The cockpit was partitioned into eight Areas of Interest (AOIs) corresponding to the primary operational displays and interaction zones of the Airbus A320 (Fig. 2). In the assisted single-pilot condition, a ninth AOI was introduced to capture gaze directed toward the tablet-based Virtual Assistant. AOI definitions were spatially consistent across participants, and samples falling outside predefined regions were excluded. Fixations were assigned to AOIs, and consecutive fixations within the same region were aggregated into dwells. The analysis focused on a short, operationally relevant flight segment surrounding the failure event, spanning from failure onset to completion of all ECAM actions required to minimally secure the aircraft (i.e., transition to the Status page). This interval captures the critical phase requiring immediate diagnostic and procedural responses.

**Results and Discussion**

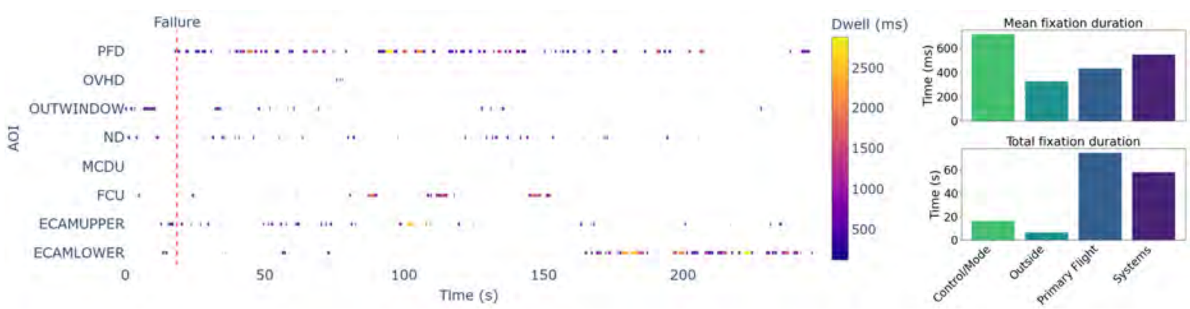
Two complementary analyses were conducted. The first examined scanpath dynamics via gaze transitions between AOIs to characterize the structure and temporal organization of visual scanning. The second quantified attentional allocation using fixation-based metrics, namely Total Fixation Duration (TFD) and Mean Fixation Duration (MFD). TFD reflects overall visual workload, whereas MFD captures the depth of visual processing. As shown in Figure 3, scanpaths are analyzed at the AOI level, whereas TFD and MFD are aggregated into functional and thematic AOI clusters to support workload interpretation in terms of



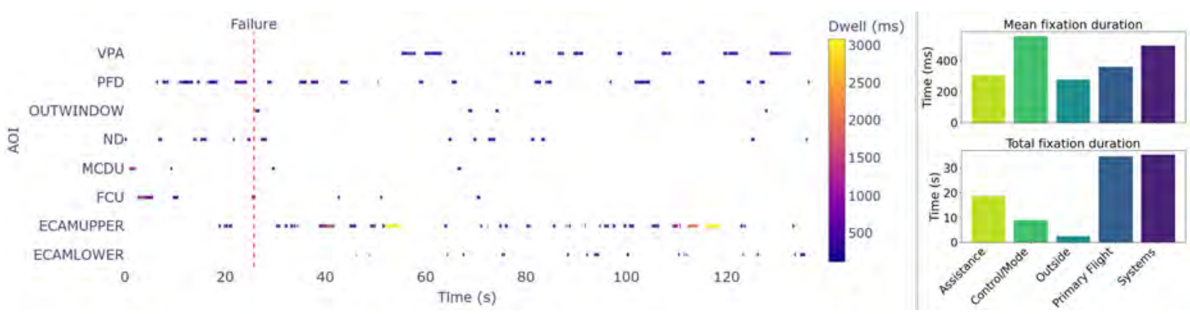

(a) Dual Pilot Configuration - Pilot #2




(b) Single Pilot Configuration (All-Alone) - Pilot #2




(c) Dual Pilot Configuration - Pilot #1




(d) Single Pilot Configuration (Virtual Assistant) - Pilot #1

Figure 3: On the left of each panel, the scanpath is shown, where small rectangles denote individual fixations on the corresponding AOI over time; the red vertical line marks the moment of failure onset. On the right, histograms report fixation metrics aggregated into thematic clusters, each grouping multiple Areas of Interest (AOIs): Primary Flight (PFD, ND), Systems (ECAMUPPER, ECAMLOWER, OVHD), Control/Mode (FCU, MCDU), Assistance (VPA), and Outside (OUTWINDOW)

general piloting functions. Analyses were conducted both across configurations and between pilots, given the fixed single-pilot condition of interest. Although the overall time window spans only a few minutes, it was sufficient to reveal meaningful differences between conditions. The pilots under analysis always acted as pilot flying, thereby retaining primary control of the aircraft and responsibility for communications.

Analysis of Pilot #2's visual behaviour indicates a strong dependence on the crew configuration. In Dual-Pilot Operations (DPO), Pilot #2 directs most visual attention to the Primary Flight instruments, with a dynamic scanpath marked by frequent transitions and short fixations, consistent with shared workload and continuous monitoring on the PFD. No gaze directed toward OVHD was observed during this condition, as these tasks are typically performed by the co-pilot. Under Single-Pilot Operations (SPO), by contrast, attention shifts markedly to the Systems cluster, which dominates both TFD and MFD. Once the failure has happened, PFD monitoring becomes sporadic, and long system-focused dwell periods emerge, especially on ECAM-UPPER and OVHD. FCU involvement decreases sharply, suggesting reduced capacity for flight-control adjustments. The mayday call was observed to occur sooner during SPO, reflecting the absence of cross-checking or probably the latent need to accelerate operations. Overall, Pilot #2's scanpath shifts from broad, high-frequency monitoring with DPO to a system-focused pattern characteristic of increased workload and reduced situational awareness (for SPO).

The same analysis can be done for Pilot #1. In DPO, attention is primarily divided between Systems and Control/Mode, with substantial engagement of Primary Flight instruments. The scanpath remains rich and continuous, supported by effective task sharing. In SPO, Systems monitoring increases—as observed for Pilot #2, yet Pilot #1 maintains recurrent transitions to PFD and ND even after the failure, preserving a more balanced monitoring loop. Scanpaths remain diversified, with short-to-medium dwell times indicative of active management of both flight-path monitoring and diagnostic tasks. The Virtual Assistant appears to redistribute, rather than intensify, workload by supporting ECAM interpretation and procedural structuring, thus reducing prolonged system-focused fixations. A notable drawback is the reduced outside-window scanning, which, although mitigated in this scenario by benign cruise-phase conditions, would not be desirable in other phases of flight. It is also relevant to remember that the pilot received minimal training with the assistant; increased familiarity may further enhance monitoring stability.

## Conclusions

This preliminary study examined changes in pilot gaze behavior during abnormal event management across dual- and single-pilot configurations. Despite the limited sample, eye tracking revealed consistent shifts in visual strategies associated with increased workload and changes in monitoring responsibilities. Future work will extend the analysis to more pilots, flight phases, and failure scenarios, and integrate gaze data with performance and workload measures. Beyond reduced-crew operations, this approach may also inform cockpit interface design, assistive tool evaluation, and training for effective monitoring.

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