# The influences of flight deck interface design on pilot situation awareness and perceived workload

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## ABSTRACT

There are numerous accidents and incidents related to mode confusion. Autothrottle and autopilot are traditionally separated systems on the flight deck, however they can interact through the physics of flight. Avionic engineers have been applying automation to reduce pilot's workload and enhance flight safety. While basic automated systems performed quite simple tasks such as holding altitude or heading, modern flight guidance and control systems typically have different modes of operation. A new flight mode annunciator (FMA) concept was compared with traditional FMA in conjunction with eye-tracking and NASA-TLX measurements. The experiment involved 17 participants, aged between 22 and 47 years (M = 29.18, SD = 6.73). The results showed that the augmented display significantly reduced the perceived workload on mental demand, temporal demand, and effort by NASA-TLX; also increasing performance and situation awareness during climbing turn on the perception of mode changing by call-out. Furthermore, participant's fixation duration has significant differences on airspeed and altitude indicators between traditional design and augmented design by adding visual cues of a green border. The relatively high cognitive effort to interpret the existing flight mode annunciation is certainly a contributing factor in mode confusion. The significant differences in fixation duration and subjective workload demonstrate the potential benefits of the proposed visualization cue on the FMA. By simply highlighting the parameters that are controlled by the automation, it greatly reduces pilot workload and enhances situation awareness in mode changing.

## KEYWORDS

Flight Mode Annunciation, Human-Computer Interaction, Mode confusion, Situation Awareness, Visual Attention

### Introduction

Pilots have to manage and monitor modes of automation as the operational environments and flight deck parameters constantly evolve and change. The design must be human-centred, and provide pilots with good situation awareness and decrease their cognitive workload. The principle of flight deck design should enable pilots to have access to the appropriate information and make a decision and take control if a technical error occurs unexpectedly (Hasse et al., 2012). The flight decks of commercial aircraft have become increasingly automated in recent years leading to an increase in the number of operational complexities related to mode confusion and automation-surprise accidents (Dekker & Hollnagel, 1999; Woods & Sarter, 1998). Many of these accidents have been directly linked to the human-computer interactions (HCI) with the flight deck design. The continuous occurrences of accidents and incidents involving insufficient situational awareness and pilot's mode confusion underline the need in the aviation industry to develop more simplistic and easy to interpret flight mode annunciators. The different layouts of the instruments and displays are designed to assist in providing good perception and understanding that different information is needed at different times (Newman et al., 2001). Therefore, the capability of human information processing to variable messages remains a keystone of safety in aviation. Furthermore, automation has fundamentally changed the pilot's role and has affected the nature and necessity of cooperation between remaining human crewmembers and systems on the flight deck (Amalberti, 1999). The complexity of human-computer interaction on the flight deck can erode for a variety of reasons and relates to accident/incident occurrences, such as the fact that each crew member has 'private' access to the flight management computers and can change the flight path independently and virtually invisible to the other (Dekker & Orasanu, 1999).

The visual information captured by eye trackers provides the opportunity to investigate the relationship between eye movement fluctuations and attention shifts while performing tasks (Ahlstrom & Friedman-Berg, 2006). Eye scan pattern is one of the main methods for assessing a pilot's cognitive process in the cockpit based on physiological measures (Ayaz et al., 2010). It can provide numerous clues concerning the mental process of decoding information perceived by pilots, such as what areas of interest (AOIs) they scan, dwell and attend (Salvucci & Anderson, 1998). Furthermore, eye movements are a sensitive and automatic response which may serve as a window into the process of the pilots' mechanism of situational awareness (SA) and reflect their mental state (Kuo et al., 2009). There are several studies which investigate pilot's situation awareness to the status of the flight mode annunciator (FMA), and the findings revealed that human monitoring performance to the dynamic changing modes is not reliable, especially if automation-induced mode changes occur. Figure 1 shows how complex the FMA can be when considering different automation modes. The labels in the red boxes depict different states that the automation can transition to. It is then up to the pilot to detect such a change by looking at the three components including Autothrottle, Roll-mode, and Pitch-mode on the FMA and AFDS status to interpret the texts on each column. The very nature of this design incorporates a fundamental problem that the FMA is not co-located with the raw-data of flight parameters (digital numbers of airspeed or altitude) and thus does not follow the proximity compatibility principle (Wickens & Carswell, 1995).


Figure 1: The complexity of information behind the FMA in the primary flight display of B-777 flight deck

There are numerous accidents and incidents related to mode confusion. Autothrottle and autopilot are traditionally separated systems on-board the aircraft, however they can interact through the physics of flight. It should be noted that for all cases documented hereafter, classic "pitch and power" monitoring would have assisted the flight crews in an early recognition of the developing danger. Endsley (1995) defines three levels of SA, closely linked with the major components within cognitive processes. The first level is to perceive environmental cues, such as warning lights in the cockpit. The second level is a process of comprehending the cues based on knowledge and experience. The third level is to predict the possible situation in the near future and project the related measurements to resolve the specific status. SA has been recognized as an essential component within a pilot's cognitive process in the domain of aviation (Sohn & Doane, 2004). Perceived workload is an important measurement in human-machine interaction, as it is related to the operator's cognitive processes and the overall system performance. It represents the "cost" for a human operator to achieve a certain task requirement (Hart, 2006). The NASA Task Load Index (NASA-TLX) (Hart & Staveland, 1988) was introduced to capture the perceived workload of the human operator by using a set of six variables; mental demand, physical demand, temporal demand, performance, effort and frustration.

## Method

### Participants

17 participants aged between 22 and 47 years (M = 29.18, SD = 6.73) took part in this study. The research was approved by the Cranfield University Research Ethics System.

### Apparatus

*Eye-tracker:* Pupil Labs eye tracker is a wearable, light-weight eye-tracking device. It consists of a headset including two cameras and software packages for capture and analysis. The headset is connected to any convenient computing device (e.g. laptop) using a USB. The headset hosts two cameras, one facing the right eye of the participant (eye-camera), the other camera capturing the field of vision (scene-camera). The eye-camera has a resolution of 800x600 pixels and a frame rate of 60 Hz. The scene-camera captures the user's field-of-view at a high-resolution (1920x1080 pixel) with a frame rate of 60 Hz connection (Kassner, Patera, & Bulling, 2014). The primary flight display was divided into 5 different Areas of Interest (AOI's) including FMA, Airspeed, Altitude, Lateral and Attitude indicators.

*Augmented Visualization on Primary Flight Display:* A virtual replica of the B777 instrument panel was used to create the basic scenarios. All scenarios were flown in "Microsoft Flight Simulator X". The Precision Manuals Development Group (PMDG) B777 expansion pack allowed authentic recreation of the B777 PFD and ND. The creation of video files for the scenario was achieved using "VSDC video editor" (v4.0.1.475). While the original recording served as a basis for the conventional layout, the augmented display style was created by setting time marks for each flight mode annunciation change in the scenario. This procedure ensured that the only difference between the two display styles was the graphically edited augmented visualization of green rectangles on the augmented flight mode annunciator (figure 2). Also, the green rectangles are in exact synchronization with the original flight mode annunciation.

***Scenario***

The aircraft was placed in a climbing left turn, intercepting the FMS desired track. This scenario exercises all flight mode annunciation fields and allows a comparison of the two display styles for different flight modes in conjunction. The subsequent five mode changes are based on the algorithm shown on the PFD. Participants have to call out for identifying the mode changes.

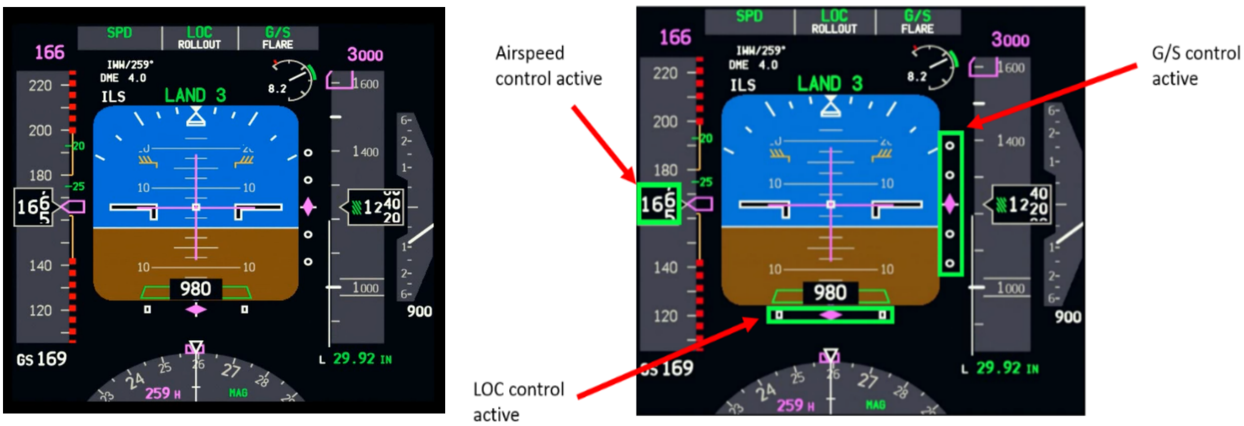


Figure 2: Traditional PFD (left) vs augmented PFD (right) on the experiment to evaluate pilot's perceived workload and SA

**Research Design**

All participants undertook the following procedures; (1) complete the demographic data including age, gender, qualifications, type hours and total flight hours (5 minutes); (2) briefing the purpose of the study and monitoring task (10 minutes); (3) sit in front of the display for calibration on eye tracker (3-5 minutes); (4) perform the monitoring task by traditional (or augmented) PFD, then rating the NASA-TLX (10-15 minutes); (5) perform monitoring task by augmented (or traditional) PFD, then rating the NASA-TLX (10-15 minutes). The experimental instructor simultaneously evaluated participants' performance of situation awareness of mode changes by recorded the numbers of call-out mode changes. It took around 50 minutes for each participant to complete the experiments.

## Results and Discussions

The length of fixation duration can reflect difficulty in extracting information (Goldberg & Kotval, 1998). A paired T-test was applied to compare participant's average fixation duration between traditional design and augmented design of PFD by eye tracker. The results demonstrated that there were significant differences in participant's fixation duration of airspeed ($t=3.432$, $p<0.01$, $d=1.240$) and altitude ($t=2.605$, $p<0.05$, $d=0.674$) between two types of design (Table 1). The augmented visualization design of PFD highlighted the information of airspeed and altitude by a green border respectively. This design can help pilots to identify the status more easily, quickly and accurately compared with traditional one, and thus to shorten the response time on cognitive process. This could be the reason why the fixation durations of airspeed and altitude on augmented PFD were significantly shorter than traditional PFD. Furthermore, the augmented visualization design on PFD could also exert positive influence on pilots' attention distribution and situation awareness. The distribution of fixations and fixation duration on relevant AOIs can be closely related to a pilot's situational awareness (Yu et al., 2014). Augmented visualization design of PFD could help to pilot's selective attention for needed useful information in current flight operations and improve situation awareness through reducing the time of perception (level-1 SA) (Endsley, 1995), thus facilitating the limited cognitive resources to process the other critical information. Therefore, pilots would have more time for understanding, projecting and decision-making to deal with tasks in hand. This phenomenon was proven by the numbers of call-out of mode changed by the augmented visualization design significantly compared to traditional design ($t=-2.524$, $p<0.05$, $d=-0.559$).

Table 1. T-test of fixation duration between traditional design and augmented visualization design on the PFD among five AOIs

| AOIs | Design | Mean | SD | N | T-Test | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | t | df | p | SE | Cohen's d |
| FMA | Traditional | 0.301 | 0.037 | 17 | 0.318 | 16 | 0.754 | 0.011 | 0.010 |
| | Augmented | 0.297 | 0.039 | | | | | | |
| Airspeed | Traditional | 0.369 | 0.075 | 17 | 3.432 | 16 | 0.003 | 0.022 | 1.240 |
| | Augmented | 0.295 | 0.054 | | | | | | |
| Altitude | Traditional | 0.488 | 0.142 | 17 | 2.605 | 16 | 0.019 | 0.046 | 0.674 |
| | Augmented | 0.365 | 0.091 | | | | | | |
| Lateral | Traditional | 0.306 | 0.128 | 14 | 1.197 | 13 | 0.253 | 0.355 | 0.320 |
| | Augmented | 0.264 | 0.038 | | | | | | |
| Attitude | Traditional | 0.408 | 0.231 | 17 | 0.637 | 16 | 0.533 | 0.043 | 0.155 |
| | Augmented | 0.380 | 0.175 | | | | | | |
| Call-out SA | Traditional | 3.001 | 0.791 | 17 | -2.524 | 16 | 0.023 | 0.256 | -0.559 |
| | Augmented | 3.650 | 0.996 | | | | | | |

NASA-TLX has been validated to assess information-processing load associated with a wide variety of tasks (Boles et al., 2007). In flight operations, this augmented design kept the same amount of information but cut the duration of cognitive process, leading to the decrease of pilots' perceptual activity and time pressure. The NASA-TLX scores demonstrated that the design of augmented visualization PFD could achieve better situation awareness by perceiving the mode changes under lower task loads. It can be found that augmented visualization PFD relieved pilots' total cognitive workload effectively compared with traditional design. There were also significant differences in participants' mental demand ($t=2.526$, $p<0.05$, $d=0.613$), temporal demand ($t=2.626$,

$p<0.05$, $d=0.637$), performance ($t=-4.079$, $p<0.01$, $d=-0.989$) and effort ($t=2.662$, $p<0.05$, $d=0.646$) between traditional and augmented visualization design (figure 3).

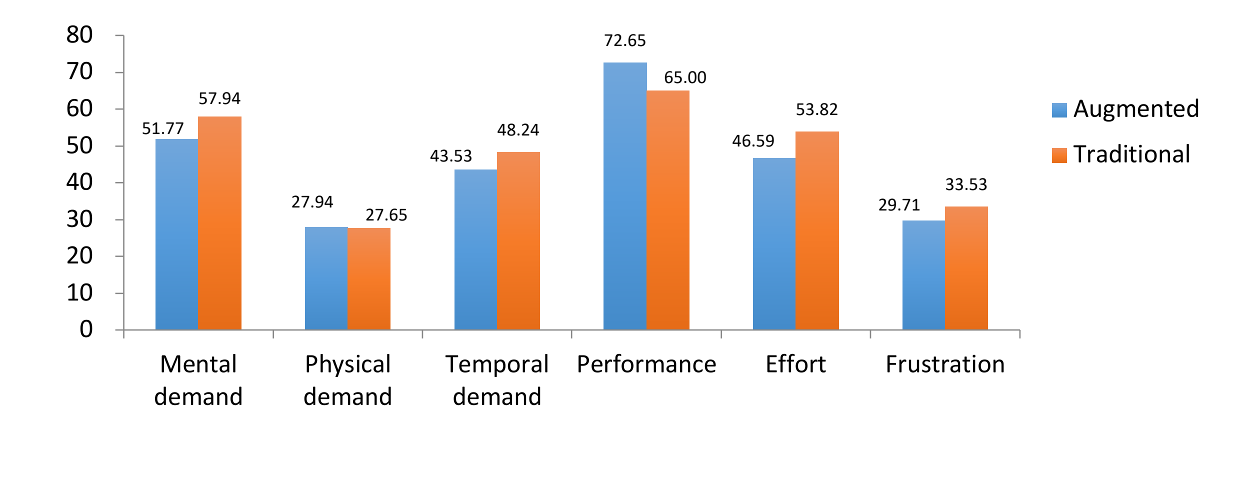


Figure 3: The comparison of perceived workload between Traditional PFD vs augmented visualization design of PFD

## Conclusion

The human-centred designs of automated aids have significant effects on human performance and cognitive processes, with increased capability to manage complex tasks. The application of eye-tracking in the study of flight deck design is promising as it provides direct feedback, which could diagnose potential factors that impact upon pilot attention and situation awareness related to cognitive processes in human-computer interactions. This research applied an objective approach of eye-tracking parameters and subjective NASA-TLX to investigate pilots' fixation duration and perceived workload comparing different designs of PFD. The main feedback obtained from participants revealed that the augmented visualization design was highly appreciated for lowering the perceived mental demand, temporal demand and effort, as well as improving performance. Most manufacturers develop designs that resemble approved ones in order to reduce pilot's workloads and improve situation awareness. It is recommended that the knowledge gained in academic research should be more readily transferred to the certification authorities and manufacturers in order to enable a more dynamic evolution of human-centred designs on the flight deck.

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