

Interface Design on Cabin Pressurization System Affecting Pilot's Situation Awareness: The Comparison between Digital Displays and Pointed Displays

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Abstract

The fundamental approach to improve pilots' situation awareness would be to reorganise and restructure the presentation of information to fit pilot's cognitive model on the flight deck. This would facilitate pilots' perception, understanding, and projection hence making it easier to find the relevant targets. Sixty pilots (30 B-737 pilots; 30 B-777 pilots) participated in this research to investigate pilots' situation awareness while interacting with digital displays and moving pointed needle displays on cabin pressurization system. The results have shown significant differences on pilots' perception, understanding and overall situation awareness between digital display and pointed display on the flight deck. Pilots significantly preferred the digital design Cabin Pressurization System which is consistent with the proximity compatibility principle, and the position of the display on the centre instrument panel is easily accessible to both pilots and does not require large head movements. There are some recommendations on the cabin pressurization design including the size of outflow valve position indicator which should be significantly increased to provided saliency of information; colour coding should be used on cabin altitude and differential pressure indicator to mark critical cabin altitude; and standard operating procedures shall include cabin altitude and differential pressure reading by pilot monitoring. The final and completed solution to the issues

on the cabin pressurization system is to redesign the scattered pointed displays as integrated digital displays to fit the human-centred principle.

Keywords: Attention Distributions; Cabin Pressurization System; Flight Deck Design; Human-Computer Interaction; Situation Awareness

1. Introduction

The occurrences of human-computer interaction (HCI) in the flight deck have been investigated for a long time, but human errors still maintain the highest percentage of contribution in aviation accidents (Harris, 2011; Schuster & Ochieng, 2014). Following several accidents involving pilot's situation awareness (SA) and HCI issues in flight operations, the Federal Aviation Administration had launched a study to evaluate flight crew and flight deck automation designs on transport category airplanes (FAA, 1996). Automation is the predominant mode of commercial aircraft operation today. Flight deck instruments are presenting not only flight path, environment and aircraft systems but also the information on automation status and active operating modes. Complex flight deck interfaces, while potentially more flexible, are also possibly more error prone. The paradigm of interface design on the flight deck is becoming increasingly important since the interface design of cabin decompression closely related to fatal accidents in aviation. According to accident statistics recently, there have been 47 cases of serious loss of cabin pressurization during a period of more than two decades (Brooks, 1987).

There are lots of accidents linked to cabin pressurization events, the most notorious accident is the Boeing 737-300 aircraft operated by Helios Airways in 2005. The aircraft departed from Larnaca, Cyprus at 06:07 for Prague via Athens. The aircraft has been cleared to FL340. During climb, the crew contacted the Operations Centre reporting a Cooling System and Take-

off warning problem. Passing 28,900 ft contact with the aircraft ended and thereafter, there was no response to radio calls. The flight continued to Athens, entered a hold in the vicinity of the destination and, after running out of fuel, impacted ground at 09:07. The 115 passengers and 6 crew members on board were fatally injured. The accident investigation report identified the following issues which contributed to this accident, including pilots unaware of the cabin pressurization selector in the manual position; non-identification of the warnings and the reasons for the activation of the warnings (Cabin Altitude Warning Horn, Passenger Oxygen Masks Deployment indication, Master Caution); incapacitation of the flight crew due to hypoxia, resulting in the continuation of the flight via the flight management computer and the autopilot, depletion of the fuel, engine flameout and the impact of the aircraft with the ground (AAIASB, 2006). The enhancement of a pilot's situation awareness is becoming a major task for interfaces designers, automation development engineers, and human factors experts in different domains of the aviation industry (Li, Zhang, Minh, Cao, & Wang, 2019).

1.1 Cabin Pressurization System Related to Major Accidents

The lower partial pressure of oxygen at altitude reduces the alveolar oxygen tension in the brain leading to sluggish thinking, loss of SA and consciousness, and ultimately death. Cabin decompression incidents are not uncommon in aviation with approximately 40-50 rapid decompression events occurring worldwide annually. Catastrophic decompression due to structural failure are infrequent, but many incidents which do lead to a rapid rise in cabin altitude might then develop as fatal accidents (Bason & Yacavone, 1992). Airworthiness Regulations regarding instruments mainly encompass requirements for what should be displayed but not how information should be presented. Regulations follow the “system-by-system” principle, which means that they are not considering the flight deck as an integrated system. Human factors certification is a process that reconciles the conflicts between the long established “engineering approach” to design with the human-centred approach to design

(Stanton, Salmon, Walker, & Jenkins, 2010). The proximity compatibility principle describes information from several sources, which are integrated as a whole picture. This principle has specific significance while assessing the status of complex cabin pressurization systems (Wickens, Hollands, Banbury, & Parasuraman, 2013).

The design of fuselage structure, decompression detection and control panel interface are not only for maintaining normal cabin pressure and a comfortable flight environment, it is also closely associated with aviation safety. Pressurization is necessary above certain altitudes to protect crew and passengers from the risk of hypoxia, altitude sickness, decompression sickness, and barotrauma. An understanding of human physiological responses and cognitive information processing can facilitate the development of solutions to eliminate human error in the processes of human-computer interactions (Chang, Yang, & Hsiao, 2016; Honn, Satterfield, McCauley, Caldwell, & Dongen, 2016). Human factors experts in the domain of aviation have defined situation awareness as the process by which the state of awareness is achieved in order to make timely decision-making in the flight deck (Li, Harris, & Yu, 2008; Sarter & Woods, 1994). To avoid human-computer coordination breakdown in the cockpit, pilots have to sustain situation awareness by understanding the status of the automatic systems related to the settings of the cabin pressurization (Funk, Lyall, & Niemczyk, 1997). Being located on right-hand side of the overhead instrument panel, cabin pressurization on B-737 lacks accessibility for both pilots. Grether (1949) investigated the errors in three needles altimeter reading, which were linked to numerous accidents and incidents. The experiment was conducted almost 70 years ago, and the results demonstrated significant differences in error rates between types of instrument designs. This provides evidence of human factors engineering which aims to establish the underlying causes of pilot error, in this case the inappropriate design on the flight deck, rather than the operator at the sharp end (Dekker, 2001; Dekker & Hollnagel, 2004).

1.2 The Evolution of Human Factors in Aviation

Breakdowns in human–computer interaction (HCI) have been a critical issue in automated aircraft (Dekker, 2000; Woods & Sarter, 2000). Recent reports from the Aviation Safety Reporting System (ASRS) administered by National Aeronautics and Space Administration (NASA) showed that HCI continues to be the substantial risk to aviation safety (NASA, 2015). The human factor in aviation is a widely researched topic and is involved in 75% of aviation accidents, which have caused fatalities and devastating economic consequences (FAA, 1996; Li et al, 2008). Based on Reason’s framework (Reason, 1990 & 1997), the detailed analysis of the human component intricated in industrial accidents can help to develop effective prevention strategies by identifying the human information processing and cognitive patterns underlying many different error types. Furthermore, Reason (2000) has presented a different view on human error by approaching human error in two ways: operator approach and system approach. The first one “operator approach” focused on the errors and accidents of the sharp-end person in the accident chain with labels like “inattentive, unprofessional, forgetful, irresponsible etc.”. This is a traditional approach and is being replaced by Reason's second approach called “system approach” which has a starting point that humans are fallible by their very nature. Human error is regarded as consequence not as a cause, taking into account human interaction at all levels, as the systems were developed, maintained and operated by humans (Reason, 1997; Wiegmann & Shappell, 2003; Li & Harris, 2007).

The integrated design based on Proximity Compatibility Principle (Wickens & Carswell, 1995) of Crew Alerting System (CAS) is significantly quicker than the conventional design on both finding the solutions and the task completion time (Li et al, 2019). Human Factors engineering is there to improve interface design by understanding operator’s cognitive processing while interacting with automation systems in the flight deck. These approaches have greater impact if applied early in the design process, long before hard-coding has begun

(Stanton & Young, 1999). It is not possible to divide the instrument design from the controls design in a flight deck because they are both part of the functioning settings where pilots perform tasks of flight operations. The term interface design will also encompass the specific procedures and checklists that structure the pilot's actions in specific phases of flight including non-normal and emergency procedures (Li et al, 2019). If human-centred concepts are not adequately integrated into the early stages of flight deck design, that might then trigger accidents in future flight operations. A human-centred approach has not been adequately examined in designing the three needles altimeter and cabin pressurization displays which is composed of different instruments located on different panels, requiring head/sight re-positioning, and which divert attention from primary flight instruments (Nikolic, Orr & Sarter, 2004).

1.3 Flight Deck Design and Situation Awareness

The fundamental approach to improve pilots' situation awareness would be to reorganise and restructure the presentation of information to fit pilot's cognitive model on the flight deck. This would facilitate pilots' perception and understanding, and projection hence making it easier to find the relevant targets. Lack of SA is a primary causal factor of human errors in aviation. Pilots' SA can be assessed by Situation Awareness Rating Technique as a subjective tool (Taylor, 1990), and visual parameters can serve as objective indicators (Dijk, Merwe, & Zon, 2011). Situation awareness could be further divided in three components: spatial awareness, system awareness and task awareness. Each of these components involves pilot interaction with the systems in the flight deck, such as spatial awareness with flight instruments and displays; system awareness with automation and aircraft systems; and task awareness for attention and task management (Wickens, 2002). According to Endsley's framework (1995a), Level 1 of SA starts with perception of relevant information. It evolves to Level 2 of SA where operator starts to integrate various elements of data related to

operational goals. This initial perception and then understanding the situations in highly dynamic operational environments will facilitate pilot's SA (level 3) to project future status to make appropriate in-flight decisions.

Björklund, Alfredson and Dekker (2006) found that flight crews used a variety of strategies to keep track of the status on the instruments related to automation in order to maintain situation awareness. The primary objective of instrument design is to enhance flight crew's situation awareness performance in all aspects of flight operations: awareness of aircraft system status, the flight path, aircraft configuration and operational environment (Endsley, 1995b). However, there are many arguments regarding the 'construction of situational awareness' and the 'meaning of loss of situational awareness' in the domain of human performance (Dekker & Hollnagel, 2004; Stanton et al, 2006; Stanton et al, 2017). Endsley (2015a) proposed that those disagreements have evolved probably because of a misconception and misunderstandings of the model of SA. Therefore, there is a continuing demand to conduct objective research on the models of SA. In order to improve pilot's performance on human-computer interactions in the flight deck, current research focusses on investigating pilots' situation awareness while they interact with digital displays of cabin pressurization system on B777 and pointed displays of cabin pressurization system on B737. This research aims to assess (1) pilots' perception while interacting with traditional pointed design (B-737) and digital design (B-777) on cabin pressurization systems; (2) pilots' understanding while interacting with different interfaces (B-737 vs B-777) on cabin pressurization systems; (3) pilots' projection while interacting with different interfaces (B-737 vs B-777) on cabin pressurization systems; and (4) pilots' decision-making while interacting with different interfaces (B-737 vs B-777) on cabin pressurization systems.

2. Method

2.1 Participants

There are 60 participants including 30 active B737 commercial pilots (21 captains and 9 flight officers) with type flight hours between 650 and 16,000 hours ($M=6,902$, $SD=3,955$); and 30 active B777 commercial pilots (17 captains and 13 flight officers) with type flight hours between 1,000 and 13,000 hours ($M=3,487$, $SD=3,037$). Approval of the Science and Engineering Research Ethics Committee of Cranfield University was granted in advance of the research taking place. All participants were informed that they had the right to cease the experiments and withdraw information they provided without any reason. The treatment of all subjects complied with the ethical standards required by the Research Ethics Regulations of United Kingdom.

2.2 Hypotheses

There were four null hypotheses investigated in this current research including (1) there is no significant difference to pilots' perception of the digital display and the pointed display of the setting of cabin pressurization system; (2) there is no significant difference to pilots' understanding while interacting between digital display and pointed display; (3) there is no significant difference to pilots' projection while interacting between digital display and pointed display; and (4) there is no significant differences to pilots' decision-making while interacting between digital display and pointed display.

2.3 Apparatus

Flight Simulator: The experiments are based on B777 simulator by Canadian Aircraft Electronics (CAE) CAE 7000 model Level D Full Flight Simulator with CAE Tropos (R) Visual System for digital design on cabin pressurization system which is to control the interior pressure and provide fresh air. B777 Cabin Pressurization System display is one compact digital instrument containing all system information and is located on the Centre Instrument

Panel between two main flight instrument panels at slightly lower than eye level (figure 1). The B737 simulator by Thales Model Concept 2000X Level D Full Flight Simulator with Tropos 6200 Series IG Visual System for pointed design on cabin pressurization system. The B737 cabin pressurization system consists three needle display and the pressurization controllers contained two automatic systems (AUTO & ALTN). If the auto system fails, the standby system will automatically take over. The AUTO FAIL light will remain illuminated until the mode selector is moved to STBY / ALTN (figure 2). The operating procedure of cabin pressurization is designed to meet FAR requirements as well as maximize cabin structure service life. The pressurization system uses a variable cabin pressure differential schedule based on airplane cruise altitude to meet these design requirements. Malfunction is inserted at 100ft in the climb which will affect the pressurization. This may not attract crew attention immediately as it is happening in very high workload phase. The first priority of the crew should be to pay attention to Cabin Pressurization when pilots called for and perform the after take-off checklist. Flight in the Terminal area involves communication and change of ATC frequencies, adherence to original and amended clearances, monitoring flight path, other traffic and weather. Workload is high with autopilot engaged and even more if manual flight is performed. This is the phase of flight where changing path, automation actions and status of aircraft systems take place.

[Figure 1 here]

[Figure 2 here]

Scenario: The scenario is comprising take-off and initial climb to deal with Cabin Pressurization System problems which depend on several factors including how early and how accurately the participants perceive and assess the pressurization abnormality, the participants

may decide to divert, return to departure airport, or continue to destination using manual cabin pressurization control. The scenario will take roughly 40 minutes in the simulator which was recorded for further analysis on pilot's situation awareness and the setting of Cabin Pressurization System. After the simulator session the pilot flight (PF) will be presented with series of snapshots of instruments and displays of the same system (digital displays vs pointed displays) followed by five operational steps for assessing participant's perception, understanding and projection to the malfunction on the cabin pressurization system (table 1).

[Table 1 here]

2.4 Research Design

Pilots perform Memory Items related to Cabin Altitude Warning/Rapid Depressurization procedures including Don Oxygen Masks, Set Regulators to 100%, Establish Crew Communication, and Go to the Cabin Altitude Warning Checklist 2.1. The instructor monitors and notes how aware the participants are of the Pressurization System operation, how much time is given to assess indications and what levels of understanding is regarding the situation around the malfunction on the cabin pressurization systems. Prior to the simulator trial, all participants undertook the following procedures: (1) participants completed the consent form with demographical variables including job title, qualifications, type hours and total flight hours; (2) presented a short briefing which explained the purposes of the study and introduced the scenario, without mentioning any potential aircraft equipment failure; (3) went through the simulator session; (4) conducted a debrief after the flight simulator trial; (5) responded to 5 operational steps while interacting with cabin pressurization system on specific type rating (B777 vs. B737); (6) exploring pilot's comments to the concept of human-centered design of the cabin pressurization displays. This experiment design is presenting participants with snapshots of the Cabin Pressurization System indications and controls based on the type rating

of simulator. Each group of participants was presented with the same scenario showing Pressurization System indications for their respective aircraft type rating, followed by the pilots' response to resolve the issues shown on digital display for B777 (figure 1) and pointed display for B737 (figure 2).

Participants viewing the snapshots is limited to 10 seconds and the response time to those issues is limited to 5 minutes due to the critical consequences of malfunction on the cabin pressurization. The time allowed to the crew assessing these issues in the scenario was recommended by Subject Matter Experts comprised of instructor pilots. There were five operational steps of human-computer interaction with the probable failures on the cabin pressurization systems (table 1). Instructor observing pilots' responses to the settings of the cabin pressurization system which reflected the pilots' perception, understanding and projection to the near future of operational environment. For example, the participant might respond to the operational step-1 with the action of revolving the cabin pressure controller to manual mode to deal with the unexpected failure. By comparing the results from parallel experiments on both B777 and B737, it can be established which type of interface design (digital displays vs pointed displays) is enhancing pilots' situation awareness. Participant's SA performance is evaluated by his responses to the snapshots of cabin pressurization systems. The statistical analysis applied independent t-test which is suitable to compare pilots' situation awareness between interacting with digital displays and pointed displays on cabin pressurization system.

3. Results and Discussions

Sixty commercial pilots (30 B737 pilots; 30 B777 pilots) participated in this research. Participants' demographic variables are shown at table 2. There are five operational steps to evaluate pilot's SA while interacted with digital display on B777 versus pointed displays on B737. Those five operational steps including step-1 related to pilot's perception on the setting of cabin pressurization system, the step-2 and step-3 are reflecting pilot's comprehension to the

situation of indications on the cabin pressurization systems, step-4 related to pilot's projection (expectation) to the near future of the figures on the cabin pressurization systems, and step-5 is reflecting to pilot's decision-making.

[Table 2 here]

All of those five operational steps are used to evaluate participant's perception, comprehension, projection and decision-making regarding the setting of cabin pressurization systems on both digital displays and pointed displays. The results demonstrated that there are significant differences in pilots' response to step-1 "perception and action to be taken on Cabin Pressure Controller" between pointed design (B737) and digital design (B777), $t=-5.722$, $p<.001$, *Cohen's d*=-1.482. The result shows that the first hypothesis is rejected. Pilots' perception had significant differences between pointed design and digital design on the cabin pressurization system. Based on step-2 "the assessment of location of Cabin Pressurization indications" indicated significant differences between pointed and digital design, $t=-17.399$, $p<.001$, *Cohen's d*=-4.498, and step-3 "location and display assessment" results show that there were significant differences between pointed and digital design, $t=-5.397$, $p<.001$, *Cohen's d*=-1.39. The result demonstrated that the second hypothesis is rejected. Pilots' understanding had significant differences between pointed design and digital design on the cabin pressurization system. On step-4 "projection of near future circumstances" has shown no significant differences between pointed and digital design, $t= 0.687$, $p>.05$, *Cohen's d* = 0.177. The result demonstrated that the third hypothesis is accepted. Pilots' projection (expectation) had no significant differences between pointed design and digital design on the cabin pressurization system. On step-5 "action taken on Outflow valve of cabin pressurization systems" there were significant differences between pointed and digital design, $t=-4.44$, $p<.001$, *Cohen's d* =-1.139

(table 3). The result demonstrated that the fourth hypothesis is rejected. Pilots' situation awareness had significant differences between pointed design and digital design on the cabin pressurization system.

[Table 3 here]

3.1 The Location of Displays Impact on Pilot's Situation Awareness

The complexity of the present flight deck is continuously increasing while at the same time there is an operator on the human side of the interface with a limited capacity to cope with the massive amount of information he/she is supposed to process. Endsley (1995b) pointed out that research has to be encouraged to explore further the psychological components of situation awareness with better analysis, experiments and by creating models that support and explain the complex construct of situation awareness. Analysis of accident and incident investigation should give important material to human factors research in establishing the role of instruments, displays and controls on the flight deck in the reduction or break-down of situation awareness. The results demonstrated that instrument design in the flight deck does have a significant impact upon pilot's situation awareness which is consistent with previous research (Endsley, 2015b).

Regarding the scenario take-off and initial climb phases, both B777 and B737 pilots had been presented with the setting of digital displays for B777 and pointed displays for B737. The cabin pressurization system on B737 consists of three separated indicators placed on two gauges located on overhead instrument panel above the First Officer position (figure 3). On the other hand, B777 Cabin Pressurization System display is one compact digital instrument containing all the system information and is located on the Centre Instrument Panel between two main flight instrument panels at slightly lower than eye level (figure 4). Working with advanced

automated systems in the flight deck, pilots not only have to monitor all the displays with efficient attention shifts, but they must also intervene if the automation systems are involved in unexpected behaviours (Bruder, Eißfeldt, Maschke, & Hasse, 2014). The path of attention distribution can reveal the cognitive process of human-computer interaction between human operators and systems (Allsop & Gray, 2014; Kearney, Li, & Lin, 2016). Therefore, a pilot's visual scan patterns on the displays can reveal human information processes and how the interface design impacts to performance (Goldberg & Kotval, 1999; Li, Kearney, Braithwaite, & Lin, 2018). B-777 pilots did demonstrate higher situation awareness on the cabin pressurization setting compared with B-737 pilots due to the location of display fitted the principle of human-centred design.

[Figure 3 here]

[Figure 4 here]

3.2 Interface Design affecting Pilots' Perception

The results from this study have demonstrated significant differences in instrument assessment and subsequent actions between pilot groups. B737 pilots did not have the correct assessment of the system status from the Step-1, 4 and 5 and as a consequence they undertook incorrect actions. Therefore, this reveals a significant absence of situation awareness on all three levels. By contrast B777 pilots have been correct in assessing the pressurization system status in the Step-1 and 5 and as a consequence their actions have been appropriate demonstrating a high level of situation awareness. There are 70% of B-737 pilots on step-1 whose response was to set cabin pressure controller to "Manual". There are 56.6% of pilots who opted for "Cabin Rate to decrease" on step-4, though there are no significant difference on the pilots' expectations between pointed design and digital design (table 3). On step-5, 60% of pilots opted for the response "Setting to 'Close' Cabin Pressure will return to normal". B-737 pilots' perception that the system status was controllable in Manual mode was an incorrect assumption. They were

incorrect to choose to close the outflow valve, as the valve has already been closed by the malfunction.

Pilots expected cabin pressure to “Decrease” as a result of previous actions which is an incorrect expectation as the cabin rate is not controlled by cabin pressure controller. The previous research has indicated that knowledge-based visual processes (top-down) play a critical role in modulating attention capture and guidance (Nikolic, Orr, & Sarter, 2004). Pilots’ perception in the flight deck can also be attracted promptly and adjusted properly depending on features of the stimulus (Blair, Watson, Walshe, & Maj, 2009), which is based on the bottom-up visual characteristics. Therefore, it is critical that unexpected malfunction stimulus stirs a pilot’s perception to make attention shifts rapidly and correctly to the suitable displays in order to make urgent responses. According to pilots’ response to step-1, B-737 pilots’ responses demonstrated less precise perception to Cabin Pressure Controller than B-777 pilots. The digital design on the cabin pressurization system integrated all the critical information to facilitate pilots’ attentional distribution for the searching of information. It reveals that digital display design on B-777 attracts pilots’ attention better than pointed display design on the B-737. The location of the overhead panel also requires head positioning away from primary flight displays. Flying and navigating tasks have overall priority over system assessment tasks, so diverting attention to the overhead panel during take-off operation is routinely excluded or minimized. Design of the Outflow Valve Indicator features a small needle and a very small size instrument, probably the smallest of all indicators in this B-737 flight deck. This design does not provide saliency of information and, as the experiment has shown, the crew have very high workload in order to process this information as initial perception of the system status.

3.3 Interface Design Impacted to Pilots’ Understanding

The purpose of cockpit interface design is to contribute to a better understanding of pilot’s cognitive mechanisms involved in data-driven attention distribution and situation awareness.

The statistical analysis had shown that pilots' comprehension level of Step-2 (assess the location of Cabin Pressurization Indications) and Step-3 (the location of Cabin Pressurization Indications affecting operation) between B-737 and B-777 groups have significant differences. It revealed that Cabin Pressurization Indications (digital display) on B-777 can assist pilots and enable them to easily grasp the real time situation on cabin pressure failure. It is consistent with previous visual behavior research that the comprehensive interface design can shorten saccadic distance to increase operators' attentional shifts and situation awareness (Yu, Wang, Li, Braithwaite, & Greaves, 2016).

There are 83.3% of the B-777 pilots who expressed no issue on assessing both auto and manual modes on the cabin pressurization system, and there is a significant correct response when compared to that of the B-737 pilots. On the "expected effects in terms of figures?", there are 80% of B-777 pilots who opted for dealing with "Cabin Rate to decrease" which is the correct understanding of the current situation. The result demonstrated that digitalization on the flight deck can significantly improve pilot's understanding the current situation on the cabin pressurization systems. The Proximity Compatibility Principle (Wickens & Carswell, 1995) can be used to explain B-777 pilot's better understanding of cabin pressurization setting than B-737 pilots, as the relevant information has to be integrated on a cluttered display and be placed in close spatial proximity which can improve operator's performance. In addition, B-777's Cabin Pressurization Indications could probably reduce diverting attention from primary tasking due to the integration of information from converging indicators. The interface design of digital display on B-777 supports pilots' situational awareness without causing other detrimental effects (Harrivel et al, 2016). The main instrument of Cabin Altitude and Differential Pressure Indicator with two needles and two gauges are confusing to B-737 pilots when interpreting the setting on the cabin pressurization, and is also lacking salient information to assess critical situations quickly. During the high workload phase of take-off and the initial climb, it is a demanding task to assess which needle is related to which scale again leading to

errors in the comprehension phase of situation awareness.

3.4 Interface Design Influencing Pilots' Projection

There are 56.6% of B-737 pilots who provided negative feedback to the location of cabin pressurization and 70% expressed their concern with regard to the location of cabin pressurization affecting their operational efficiency. What B-737 pilots' feedback indicates is that the position of the pressurization system display might be an important factor affecting their situation awareness performance, for the position of B-737 cabin pressurization is on the top of right-hand seat where it is not easy for the pilots to observe. On the other side, B-777 pilots had the same scenario with the same setting values of indications on their cabin pressurization displays. There are three stages of information processing involved in pilots' decision-making, these are cue perception, diagnosis, and choice (Wickens & Hollands, 2000). It indicates that the features of the cabin displays can influence the quality of pilots' decision-making starting with the presentation of the failure cues in order to attract the pilot's attention, understanding what cues are relevant to what issues, forming multiple options and projecting the proper corrective intervention to resolve the malfunction. The results of Step-5, indicated that B-777 interface design might help the pilot determine the correct control input a great deal. After take-off the pilot has to re-configure the airplane (landing gear and flaps), fly the airplane (manually or with autopilot), navigate, communicate and monitor other traffic. Monitoring the system status is not his priority at this event. These five steps are sufficient to reproduce the operational settings of cabin pressurization systems regarding take-off and climbing without memory decay, as found by Endsley (1995b).

Pilots' responses to all situations were focused on their evaluation of what was the appropriate setting presented on instruments, displays and control panels. This has been accomplished by comparing pilot's responses to suitable instrument indications to reflect the status of aircraft. The comparison of actual indications and the perceived situation has provided an objective

measure of situation awareness. The better human centered integrated design on the cabin pressurization is the type on B-777. It is located in the centre of the instrument display accessible to both pilots without diverting attention from primary flight instruments. The display contains quality information, already processed by the system, thus reducing the pilot's cognitive workload to process those information. Colour coding is used to indicate the status of cabin pressure system; pictorial presentation of relevant information is available at a glance, and information of highest importance is given visual priority grabbing the focused attention (Ltifi, Kolski, & Ben Ayed, 2015).

4. Conclusion and Recommendation

The purpose of this study is to explore the impacts of instrument design with regard to pilot's situation awareness. By applying flight simulator scenarios to this research, it is applicable to approach pilots' perception, comprehension and projection to the setting of cabin pressurization systems. The results have shown significant differences on pilots' situation awareness between digital display and pointed display on the flight deck. The B737 Cabin Pressurization System and associated controls has lacked some of the basic important principles of human-centered design. The location of five elements of the system (three instruments and two controls) on the overhead panels has not followed the proximity compatibility principle. Perceptual proximity solution (position of two sources conveying the task-related information) and processing proximity (defining how the sources have to be integrated in task performance) have not been applied in the design of these system indications compared with B-777 digital display. The B-777 display design is consistent with the Proximity Compatibility Principle in both spatial (all relevant indications on one single integrated display) and processing proximity (the integration of sources related to the task). The position of the display on the centre instrument panel, does not require dramatically changing head position and is accessible to both pilots. The position of the digital design on the cabin pressurization system makes this information available even

when attention is mainly allocated to the flying task. There are some recommendations on the cabin pressurization design based on this research as following, (1) all indications should be located on one panel to be accessible to both pilots; (2) size of outflow valve position indicator should be significantly increased to provided saliency of information; (3) colour coding should be used on cabin altitude and differential pressure indicator to mark critical cabin altitude; (4) standard operating procedures shall include cabin altitude and differential pressure reading by pilot monitoring. The final and completed solution to the issues on the cabin pressurization system is to redesign the scattered pointed displays as integrated digital displays to fit the human-centred principle and located at the centre of flight deck.

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Boeing 777 Cabin Pressurization System Display



Boeing 777 Cabin Pressurization Control Panel

Figure 1. Illustrated cabin pressurization malfunction of Boeing 777 during take-off and initial climb operation



Boeing 737-800 Cabin Pressurization System Display



Boeing 737-800 Cabin Pressurization Control Panel

Figure 2. Illustrated cabin pressurization malfunction of Boeing 737 during take-off and initial climb operation



Figure 3. The position of B-737 cabin pressurization on the top of right-hand seat in the flight deck shown as red circle



Figure 4. The position of B-777 cabin pressurization in the center of flight deck shown as red circle

Table 1. Five operational steps related to human-computer interaction on the malfunction of cabin pressurization system

Steps	Content
1	What action would you take on cabin pressure controller?
2	How do you assess the location of Cabin Pressurization Indications based on the significance of the effect?
3	How is the location of Cabin Pressurization Indications affecting its operation based on the significance of the effect?
4	What effect you expect in terms of figures on the displays?
5	What action would you take on the outflow valve in terms of scenario figures?

Table 2: Participants' qualifications and flight hours of Boeing 737 and Boeing 777

Variables	Groups	Aircraft Types	Frequencies
Qualification	Captain	B737	21 (70%)
		B777	17 (56.6%)
	First Officer	B737	9 (30%)
		B777	13 (43.3%)
Total Flight Hours	1000 and less	B737	0 (0%)
		B777	0 (0%)
	1001-2000	B737	1 (3.3%)
		B777	0 (0%)
	2001-5000	B737	4 (13.3%)
		B777	12 (40%)
	5001 and above	B737	25 (83.3%)
		B777	18 (60%)
Type Flight Hours	1000 and less	B737	1 (3.3%)
		B777	0 (0%)
	1001-2000	B737	1 (3.3%)
		B777	17 (56.6%)
	2001-5000	B737	10 (33.3%)
		B777	4 (13.3%)
	5001 and above	B737	18 (60%)
		B777	9 (30%)

Table 3. T-test of pilots interacted with digital display (B777) vs pointed displays (B737) on cabin pressurization systems

Operational steps	Behavior Dimensions	Aircraft Types				<i>T-Test</i>				
		A(B-737)		B(B-777)						
		M	SD	M	SD	<i>t</i>	<i>df</i>	<i>p</i>	<i>SE</i>	<i>Cohen's d</i>
Step-1	Perception	1.50	0.82	2.67	0.76	-5.722	58	<.001	0.204	-1.482
Step-2	Comprehension	1.60	0.86	4.87	0.57	-17.399	50.59	<.001	0.188	-4.498
Step-3		1.50	0.94	2.93	1.11	-5.397	56.39	<.001	0.266	-1.39
Step-4	Projection	1.97	0.67	1.87	0.43	0.687	58	.495	0.146	0.177
Step-5	Decision-making	1.77	0.97	2.73	0.69	-4.44	52.39	<.001	0.218	-1.139

Interface design on cabin pressurization system affecting pilot's situation awareness: the comparison between digital displays and pointed displays

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