

Touchscreen Controls for Future Flight Deck Design: Investigating Visual Parameters on Human-Computer Interactions between Pilot Flying and Pilot Monitoring *

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ABSTRACT

This study is concentrated on investigating the different visual behaviors and HCI patterns between pilot flying and pilot monitoring while interacting with touchscreen controls on the flight deck. Twelve participants with flight experiences ($M=1150$, $SD=4019.9$) attended this research. The apparatus included Future Systems Simulator (FSS), eye tracker, and system usability scale (SUS). The designated scenario in the experiment was an instrument landing. All participants were required to perform two instrument landings in two different roles, pilot flying (PF) and pilot monitoring (PM). The order of role of randomized to eliminate practice effects. The results revealed that fixation counts of pilot flying were different among four AOIs, $F(3, 9) = 10.58$, $p = .003$, $\eta_p^2 = .78$. On the other hand, the FC of pilot monitoring demonstrated a significant difference among four AOIs, $F(3, 8) = 8.69$, $p = .007$, $\eta_p^2 = .77$. There was a significant difference between PF and PM on the subjective assessment of SUS total score, $t(11) = 3.85$, $p = 0.003$, Cohen's $d = 1.11$. The application of a touchscreen can integrate input and output in the same area for visual feedback. There is a rising need to simplify the future flight deck design based on the principle of human-centered design. **Conclusion:** The application of touchscreen flight controls may have the potential to facilitate single-pilot operations flight deck design in the future. TSCs considerations must be consistent with human information processing and pilots' operational characteristics on the future flight deck.

Keywords: Future System Simulator, Human-Computer Interactions, System Usability, Touchscreen Controls, Visual Attention

I. INTRODUCTION

The implementation of touchscreen on a modern flight deck has been investigated for a long time. However, there were potential risks on touchscreen components associated with inadvertent touches in both normal and emergent situations, which may be defined as system-detectable touch issued to the touch sensors without the pilot's operational consent [1]. Handling qualities on the flight deck design has developed hand in hand with the discipline of flight control engineering since the beginning of aviation. Methods and tools for system usability

assessment have evolved with significant progress in flight control design. A traditional handling qualities engineer has so far focused on flight control architecture, stick feel systems, and experimental testing (design, execution, and analysis) for demonstrating performance while, at the same time, interacting with various engineers from all disciplines to ensure the aircraft can satisfactorily perform all missions. An innovative development on human-computer interaction (HCI) for future flight deck design the interface with human factors engineers in the implementation of touchscreens as control inputs. Not much has been changed from the pilot's perspective with

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regard to using touchscreens on the flight deck of large commercial transport aircraft so far [1, 2].

Currently, there are ongoing innovative developments associated with the next generation of flight deck design which has explored the application of touch screens. This paper focuses on multifunction touchscreen controls (TSCs) for future flight operations, as it is important that system usability and human factors considerations are studied in realistic operational environments. To ensure the integrity and reliability of these complex mechanical systems, the pilot flying (PF) and the pilot monitoring (PM) must conduct cross-checks by moving their eyes for visual attention and hands for action executions to the control levers/switches on different positions. The application of touchscreen technology on the flight deck can reduce pilots' head-down time and increase operational safety by integrating action executions of control inputs and visual attention on the consequences of their inputs. However, TSCs in the flight deck may also create some safety concerns during hazardous situations (such as turbulence), which are stressful for pilots [3]. Therefore, the implementation of TSCs on the flight deck must demonstrate high usability and safety with regard to human-centered design so as to satisfy regulators' requirements.

Nomenclature

AOIs	Area of Interests
CD	Checklist Display
CUD	Central Upper Display
FC	Fixation Count
FD	Fixation Duration
FSS	Future System Simulator
HCI	Human-Computer Interaction
ILS	Instrument Landing Scenario
ND	Navigation Display
PD	Pupil Dilation
PF	Pilot flying
PFD	Primary Flight Display
PM	Pilot monitoring
SOPs	Standard Operating Procedures
SPO	Single Pilot Operation
SUS	System Usability Scale
TSCs	Touchscreen Controls

II. RELATED WORK

Modern technologies have paved the way for the ability to recreate realistic scenarios in the safe environment of a laboratory or flight simulator. Developments and research in flight simulation technology between industries and academia have resulted in the Future Systems Simulator (FSS), which is a touchscreen-display flight simulator that can model all types of advanced aircraft. While it shows many promises, one must consider human factors challenges on pilots' situation awareness and system usability [1, 4]. Innovative technologies implemented on the flight deck shall

demonstrate its capacity on increasing pilots' performance by executing many complex tasks simultaneously, including information processing, system monitoring, diagnosing potential risks, and controlling the aircraft [5, 6].

2.1 Touchscreens implemented on the flight deck

Touchscreens offer intuitive interactions, flexible information displays, and intuitive operations requiring little cognitive resource by direct manipulation and easier hand-eye coordination [7]. While interacting with a touchscreen, the human operator does not have to look to another display to see the results of their input, as would be traditionally required when using a mechanical knob or button [8]. Touchscreen technology can mimic the direct manipulation of mechanical components via the display and offers the potential for reducing pilots' workload with easy manipulation capabilities and improved visual attention distributions between various formats. In commercial aviation, the use of touchscreens allows the cockpit information to be displayed with clearer and neater menus on a larger, customizable interface. The use of touchscreens in the flight deck has been steadily increasing; however, their usability may be severely impacted when turbulent conditions arise [3, 9].

There were some safety concerns about the application of touchscreens on the flight deck. Unlike most physical input devices, such as buttons, knobs, switches, and mice, touchscreens provide no information on shape, texture, mechanical movement, or kinesthetic feedback. This lack of feedback has been demonstrated to result in slower responses and less accurate performance. Furthermore, touchscreen usage suffered greatly in turbulence conditions, such as task completion time increased by 38-70%, and the error rate was 4 to 5 times higher than in static conditions [10]. In order to improve touchscreen entry speed and accuracy, a number of designs on visual, auditory, and tactile feedback have been suggested. Visual feedback can take various forms, such as highlighting the component being pressed or pop-up keys on a keyboard. These designs have been shown to facilitate touchscreen usage [11]. Abundant literature has investigated how the age of the user, the layout of the interactive item, and the size of the touchscreen affected the determination of the target size. In contrast, touchscreen specifications for flight deck applications are still evolving, and the HCI requirements are not fully established [12].

2.2 Pilots' visual behaviors on the flight deck

Pilots' visual behaviors can be investigated using eye-tracking technology to assess cognitive perceived workloads and system design on the flight deck [13]. Visual parameters are the most effective approaches for assessing a pilot's cognitive information processing in HCI research [14]. Furthermore, eye movements are a sensitive and automatic response that may serve as a window into the process of pilots' mechanism of situational awareness (SA) and reflect their mental state [15]. Fixation is defined as the eye movement pausing over an informative stimulus for the purposes of interpreting the

information [16]. Fixation duration is the average time for fixations on an area of interest (AOI), such as the Checklist Display on the flight deck. Fixation duration, similar to the number of fixations and dwell time, represents the relative engagement with the object. The longer the fixation duration, the greater the level of engagement [17]. The patterns of fixations on the AOIs related to pilots' attention distributions on the flight deck for information processing among display systems [18]. Fixation duration is the total time fixating on an instrument that can reflect the level of importance or difficulty in processing information [19].

2.3 Assessment of system usability on TSCs

The human-centered design of the flight deck has been cited as a desirable goal that should focus on supporting the system designs matching the operational characteristics of both PF and PM. The design philosophy provides guidelines to direct decisions concerning the interaction of the flight crew with the aircraft systems, such as the allocation of functions between pilots and systems [20]. Although the implementation of innovative technologies may solve some problems on the flight deck, it often introduces other new HCI issues that might not have been foreseen. These HCI issues must be considered in a wider context on considerations of implementing touchscreens for future flight deck design. There are several advantages to introducing a touchscreen to future flight deck designs. The most obvious is its excellent structured levels of integration on different layers of systematic information [21]. Reducing the visual distance between input and output allows for a better division of functional blocks and a reduction in pilots' workload [22] and enhances the simplicity of the flight deck layout, making it easier to update [23]. However, there are disadvantages of safety concerns on the implementation of touchscreen on flight decks proposed by previous research, including the accuracy of touchscreen operation significantly reduced in the vibration conditions and fatigue [9, 10, 13]. Several studies are currently trying to solve these problems for future applications [2, 24].

III. METHOD

3.1 Participants

Twelve participants with flight experience ($M=1150$, $SD=4019.9$) attended this research. All participants were required to sign the consent form prior to the experiment. The ethics approval had been granted by research institution's ethics committee before conducting the experiment. Participants were also informed that they had the right to terminate and withdraw from the experiment at any stage, even after the data collection phase. This research has followed the data protection act, which is the UK's implementation of the general data protection regulation (GDPR).

3.2 Apparatus

Future Systems Simulator (FSS): Rolls-Royce and Cranfield worked with DCA Design International to the

development of FSS and ensure the design of FSS that would fulfill its research requirements. The FSS won the internationally acknowledged iF DESIGN AWARD, which distinguished the design of FSS as a testbed for future flight deck and awards one of the most important seal of quality in the world in 2021. The FSS is a highly reconfigurable modular flight simulator with information presented on up to four large touchscreens and two smaller side screens. This allows pilots to explore the potential impact on future flight deck design for single-pilot operations, including smarter, more autonomous engines, as well as revolutionary new technologies.

Pupil Labs eye tracker: A lightweight eye tracker which consists of a headset and two cameras for collecting participants' visual parameters. The eye camera is connected to the eye camera via the ball joint allowing six degrees of rotation to get a precise image of the eye. The world camera can rotate up and down to align with the participant's field of view (FOV). There are four AOIs as follows: Primary Flight Display (PFD), Navigation Display (ND), Checklist Display (CD), and Central Upper Display (CUD). The eye tracker's 'world camera' is mounted on the right top of the headset, showing the orientation and view of the participant's FOV, and the eye camera is mounted offset right and low. It is adjustable to suit the different facial layouts and track pupil parameters. These two cameras have to be calibrated and synchronized precisely for data collection and analysis (Figure 1).

System Usability Scale (SUS): SUS offers a quick and reliable for measuring the usability of a wide variety of products, including hardware, software, mobile devices, and applications. It consists of a ten-item questionnaire with five response options for respondents [25]. SUS also provides a global measure of system satisfaction and sub-scales of usability and learnability. Items 4 and 10 provide the learnability dimension, and the other eight items provide the usability dimension [26]. Applied SUS is to investigate the HCI experience between PF and PM while interacting with touchscreens in an instrument landing scenario (ILS).

3.3 Research design

The designated scenario on the experimental design is an instrument landing task in which participants were required to interact with flaps, landing gear, spoilers, and checklists using touchscreen controls located in different areas in the flight deck (Figure 2). Based on the standard operational procedures (SOPs), pilot flying is expected to coordinate with pilot monitoring to perform cross-checks. All participants were required to perform two instrument landings in two different roles, pilot flying (PF) and pilot monitoring (PM), in random order to eliminate practice effects. PF would primarily interact with the PFD to maintain the desired descent rate and perform a stabilized final approach by aviating the aircraft with a sidestick. Furthermore, PMs are required to interact with the digital levers on CUD, validate the flight route of the aircraft on the navigation display, and conduct the checklist based on Checklist Display (Figure 3).

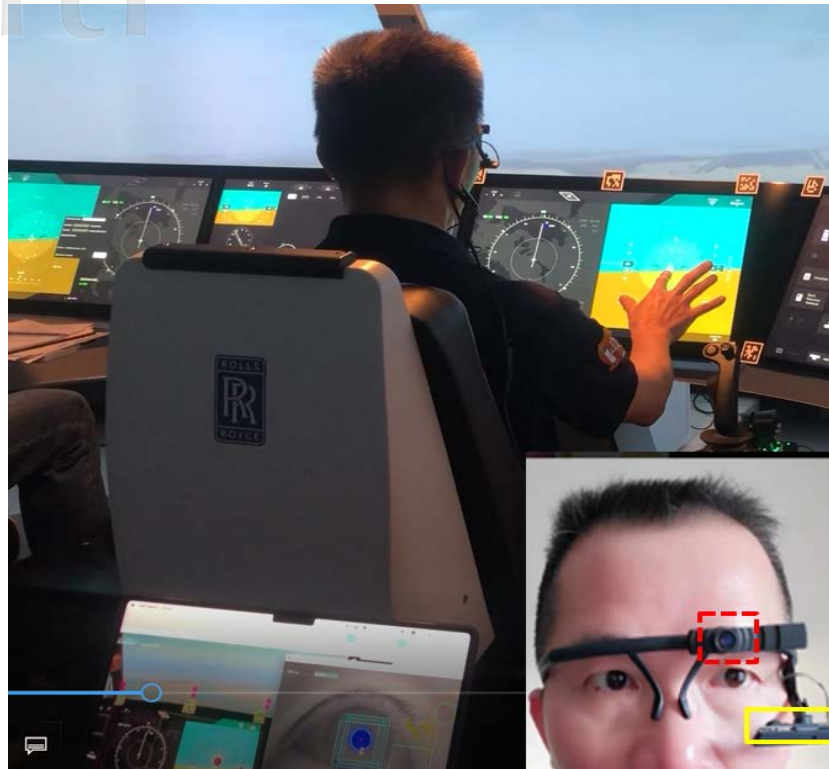


Figure 1 Participant wearing Pupil Labs eye tracker synchronized both world-camera (red box) and eye camera (yellow box shown on the left-hand side bottom) conducting calibration with touchscreen displays (index finger on the PFD) in the flight deck of FSS.

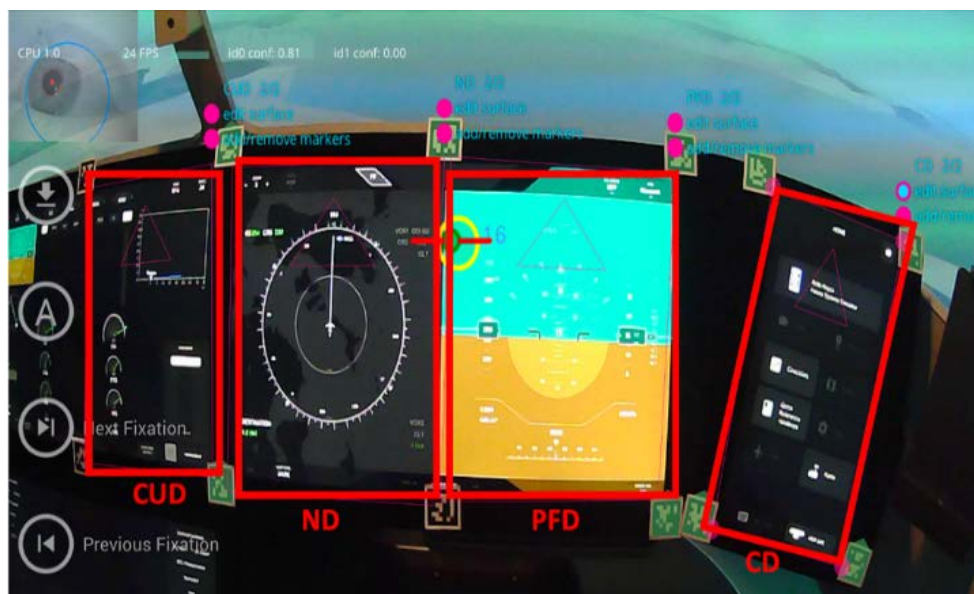


Figure 2 Pilots (PF & PM) interacting with four main touchscreen displays marked as red color on final approach on instrument landing scenario

This research involved assessing HCI in flight operations using an innovative touchscreen interface in the FSS and eye tracking device. All participants undertook the same processes as followings; (1) completed the demographical data including age, gender, working experience, and total flight hours (5 minutes); (2) briefing

the purpose of the study and familiarized with touchscreen layouts (15 minutes); (3) seat in the simulator for calibration of the eye tracker where the world camera would be adjusted to ensure the entire area for calibration was within the world camera's FOV (5-10 minutes); (4) perform the scenario on instrument landing twice: as a PM

and PF, randomly to eliminate practice effects (10-15 minutes); (5) assessing system usability scale (SUS) on TSCs in flight deck (3-5 minutes); (6) debriefing and

providing feedbacks (5-10 minutes). It took around 60 minutes for each participant to complete the experiments.

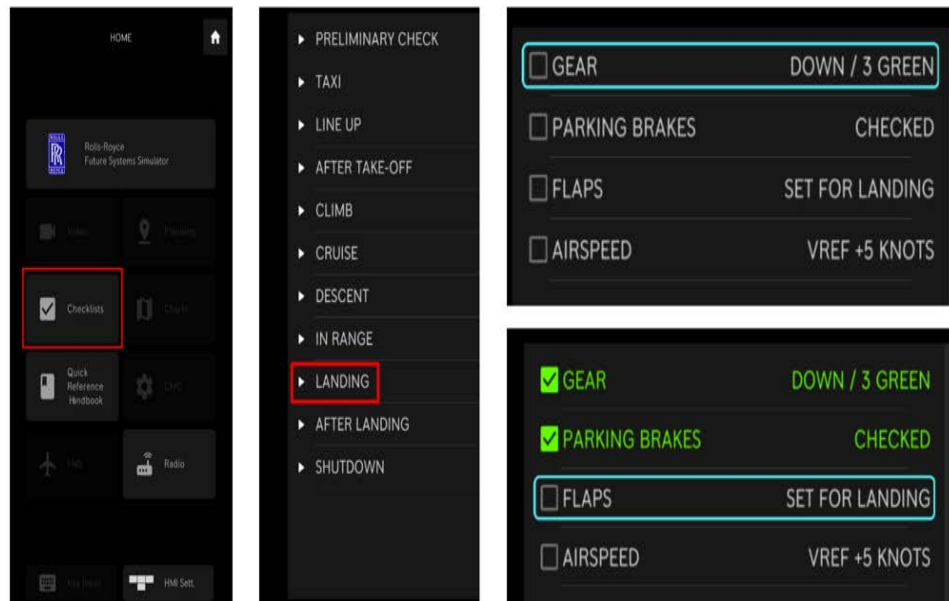


Figure 3 PM interacting with CUD touchscreen display on checking SOPs and cross-checking with PF on instrument landing scenario

IV. RESULTS

4.1 Sample characteristics

Based on the experimental design, participants performed the task as both PF and PM wearing the eye tracker to collect visual parameters while interacting with touchscreens on the flight deck. Therefore, participants' visual parameters, including both fixation duration (FD) and fixation count (FC) among four AOIs, including Primary Flight Display (PFD), Navigation Display (ND), Checklist Display (CD), and Central Upper Display (CUD) were examined by repeated measure analysis of variance. The assumption of sphericity was examined in terms of Mauchly's test. Post-hoc analysis was performed using the Bonferroni correction after a significant effect was confirmed. Furthermore, the system usability scale (SUS_{total}), including Learnability (SUS_L) and Usability (SUS_U), were examined based on both PM and PF positions after participants completed the simulator trials. The descriptive statistics of FC and FD among four AOIs and system usability scales of touchscreen applications are shown in Table 1.

4.2 PF and PM's visual parameters among AOIs

To evaluate the visual attention between PFs and PMs on the touchscreen displays in the FSS, the RM_ANOVA with four AOIs as the factor was computed.

The results revealed that FC of PFs was different among four AOIs, $F(3, 9) = 10.58$, $p = .003$, $\eta^2 = .78$. Bonferroni post-hoc comparison suggested PFs had significantly more fixation numbers on PFD than CD, CUD and ND; and more fixation counts on ND than CD.

The FC of PMs also demonstrated a significant difference among four AOIs, $F(3, 8) = 8.69$, $p = .007$, $\eta^2 = .77$. Bonferroni post-hoc comparison suggested PMs fixated on PFD more frequently than CD, CUD and ND (Figure 4 & Table 1).

Table 1 Descriptive statistics (M & SD) of participants' visual parameters (FC & FD) and assessment on system usability of touchscreen application for future flight deck design

Measures	PF			PM		
	N	Mean	SD	N	Mean	SD
CD_FC	12	3.83	6.87	11	54.18	15.37
ND_FC	12	21.17	13.19	11	59.64	71.89
CUD_FC	12	19.58	22.56	11	50.27	11.87
PFD_FC	12	120.75	75.47	11	119.64	65.40
CD_FD	12	171.02	137.14	11	252.21	32.44
ND_FD	12	244.37	36.82	11	249.57	59.82
CUD_FD	12	248.10	44.90	11	245.36	48.76
PFD_FD	12	302.79	76.39	11	302.62	61.71
SUS-L	12	10.00	5.93	12	12.08	4.98
SUS-U	12	46.67	15.20	12	63.33	10.78
SUS-Total	12	55.42	19.36	12	75.42	13.56

Note: There was a missing data on PM's visual parameters (FC & FD) due to the calibration issues

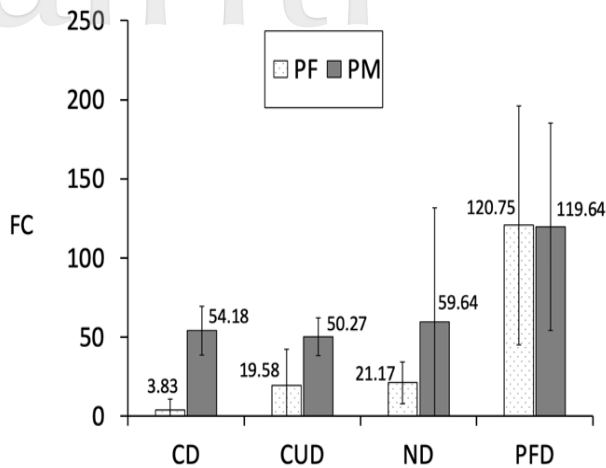


Figure 4 Fixation counts among four touchscreens between PFs and PMs while performing instrument landing

The results revealed that FD of the PFs was different among four AOIs, $F(3, 9) = 10.10$, $p = .003$, $\eta_p^2 = .77$. Bonferroni post-hoc comparison suggested that PFs had significantly longer fixation duration on PFD than CD, CUD and ND, longer fixation duration on CUD than CD. The FD of PMs also demonstrated a significant difference among four AOIs, $F(3, 8) = 5.57$, $p = .023$, $\eta_p^2 = .68$. Bonferroni post-hoc comparison suggested PMs had significantly longer fixation duration on PFD more frequently than CD, CUD and ND (Figure 5 & table 1).

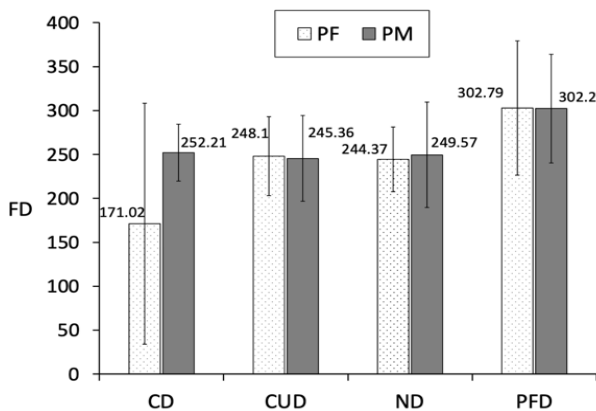


Figure 5 Fixation duration (msec) among four touchscreens between PF and PM while performing instrument landing

4.3 Assessment of system usability between PF and PM

A paired-sample t-test was conducted to compare the feedback between pilot flying and pilot monitoring on system usability (including two sub-dimensions on both Learnability and Usability) of touchscreen applications in an instrument landing scenario. There was a significant difference between PF and PM on Usability (SUS_U) of touchscreen application, $t(11) = 3.58$, $p = 0.004$, Cohen's $d = 1.03$. However, there was no significant difference

between PF and PM on Learnability (SUS-L), $t(11) = 1.56$, $p = 0.147$, Cohen's $d = 0.45$. There was a significant difference between PF and PM on the subjective assessment of SUS total score, $t(11) = 3.85$, $p = 0.003$, Cohen's $d = 1.11$ (Figure 6).

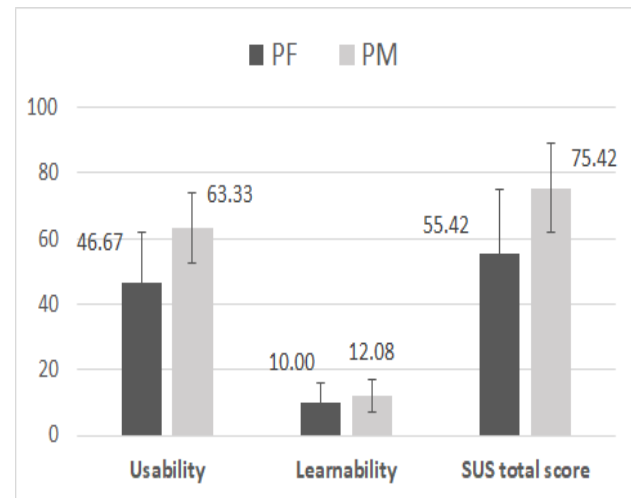


Figure 6 PF and PMs' assessment on the system usability of touchscreen applications in instrument landing scenario

V. DISCUSSION

This study is concentrated on investigating the different visual behaviors and HCI patterns between PF and PM while interacting with touchscreen controls on the flight deck. Within the arm's dynamic reach zone of PF and PM, there is a dazzling assortment of switches, levers, buttons, and screens, containing hundreds of user interface elements with different functions and packed tightly together with only the most minuscule of labels or symbols. There is a rising need to simplify the future flight deck design based on the principle of human-centered design. There are objective data of visual parameters and subjective data of SUS collected on both pilot flying and pilot monitoring positions. It is suitable to define the research scope on the landing phase, which is associated with an increase in the crew's workload and communication for cross-checks between PF on maneuvering the aircraft and PM on monitoring both automation systems and the consequences of PF's actions using touchscreen controls for future flight deck designs.

5.1 Different visual behaviors between PF and PM while interacting with TSCs

The touchscreen could be potentially applied to improve human performance in the flight deck if it followed human-centered design principles. While advanced technology shows many promises, aeronautical engineers must consider HCI challenges and pilots' operational behaviors and limitations [4]. This research demonstrated that both PF and PM's visual parameters among four touchscreens were different while interacting with touchscreens on instrument landing. PFs had more

fixation counts on visiting PFD than CD, CUD, and ND (Table 1 & Figure 4). The result revealed that PFD might be the main source of information for an instrument landing since all the flight information on maintaining the aircraft attitude (angle of attack, airspeed, altitude, vertical speed) was displayed on the PFD. Additionally, PFs focused on ND more frequently than CD. On the other side, PMs visited PFD (119.64) more frequently than CD (54.18), CUD (50.27), and ND (59.64). This could be due to the fact that PMs had to conduct cross-checks on the SOPs and validate PFs' actions affecting aircraft configuration with a checklist display. Therefore, PMs needed to validate SOPs by checking CD, CUD, and ND more often than PFs to ensure the aircraft is stable on the final approach. In summary, the FC of PFs is fewer than that of PMs on those three AOIs (CD, CUD & ND) on the flight deck, but PF had more FC on the runway and precision approach path indicators (PAPIs) than PM.

The results also demonstrated that PF and PM have significantly different fixation duration among the four AOIs (Table 1 & Figure 5). PFD might be the main source of information for PFs on instrument landing, while all the critical information related to flight operation was presented on this AOI. Similarly, PMs focused on PFD with longer fixation duration than CD. Furthermore, the results reveal that the fixation duration at each AOI for PFs

is roughly equal to PMs, except CD, in which PMs had a longer fixation duration than PFs. Such findings provided valuable information regarding the minimal fixation duration that was necessary for PFs and PMs to extract information from CUD, ND, and PFD are roughly equal. On the other hand, as a PM, the fixation duration required to extract information and validate cross-checks to PFs' operational behaviors from CD was longer. In summary, aggregation of visual fixations over time is known as a heatmap, which indicates the total amount of time spent to process the information in one AOI. Heatmap was used as complementary information to demonstrate the number of fixations and the fixation duration and never alone because a variation of fixation time could infer a change in either the fixation duration or fixation counts [2, 27]. Currently, PF and PM perform different tasks related to control inputs and control outputs monitoring in the flight deck. The PF's primary obligation is to fly the aircraft, and the PM's main responsibility is to monitor the aircraft's flight path and to immediately bring any safety concerns to the PF's attention, including radio communications, aircraft systems, and other operational activities. Therefore, there are differences between PF and PM on the attention distributions among AOIs shown as a heatmap in the flight deck (Figure 7).



Figure 7 The heatmaps of PFs (left) demonstrated their visual attention mainly focused on the runway, PFD, and CUD; PMs (right) moving among four AOIs and the center of the runway while interacting with touchscreen controls on the instrument landing scenario

5.2 Different perceptions of system usability of TSCs between PF and PM

The innovative touchscreen applications have changed conventional HCI on the flight deck. Technological evolution has provided touchscreen applications with an increasing level of "accuracy" and "stability" on the flight deck. The trial of touchscreen control inputs on the FSS is a preliminary concept for future flight deck design to explore the potential for further application. Implementing touchscreens into flight control systems offers several potential advantages to aircraft manufacturers, airlines, and pilots. However, vibration and turbulence are challenges to reliable interaction [1, 12]. The PF had decreased touchscreen interactions because their main task was flying the aircraft. That might be a causal factor of PF providing lower SUS scores due to a

lack of tactile feedback when compared with PM, who had more interactions with CD and CUD. The finding on the lack of physical feedback related to lower ratings on SUS is consistent with previous research [28]. Furthermore, the sub-dimension of Usability on PFs (46.67) might be the limited cognitive resources for utilizing an unfamiliar control input in flight operations compared with PMs (63.33). However, there was no difference in the sub-dimension of Learnability between PF and PM (Table 1 & Figure 6). In conventional flight training, pilots must learn how to use the traditional levers and switches to turn them up or down, left or right, and push or pull. That makes it difficult to remember all procedures and can be confusing when interacting with dozens of physical cockpit elements placed next to each other. On the other hand, the touchscreen interface is very straightforward by 'touch' to

activate the designated functions. It is much easier to use intuitive touchscreens than traditional flight deck control levers/switches/knobs. However, it will still require training, as Usability scores were somewhat in the middle of the scale, both for PM and PFs. Previous research has demonstrated that users tend to put 15-16% higher scores for systems they are already familiar with [29]. This observation, along with the fact that PF had less interaction with the touchscreen, showed the decrease in usability. Had the pilots been trained in using the touchscreen environments, the SUS scoring could be better in the future. There has been research that the glass cockpit offers a potential in replacing physical switches, gauges, and indicators, and that touchscreens can reduce head-down scan time, decrease workload and increase SA and safety [9]. Moreover, the touchscreen technology has already been proven to perform at least as good as the other alternatives, if not better [30-32].

5.3 The evolution from a two-seats flight deck to a future single-pilot operation

In the design of Human Machine Interfaces, simplicity is relative to the end users and the product's use cases [33]. The flight deck is a classic example of interfaces built for pilots in life-threatening situations. The designers of touchscreens must be aware of the natural limitation of human beings' cognitive processes to create a human-centered system that can process all necessary information to meet the needs of pilots in hazardous

situations [6]. However, pilots are highly trained to coagulate their mental model of the flight deck layout. Flight deck design is at the junction of aeronautical engineering and human factors integration for developing the best-fitted human-machine interfaces. Pilots can interact with the touchscreen control panels containing different systems (CD, CUP, ND & PFD) to control the landing gear, flaps, speed brakes, and light switches, which serve as the user interfaces to many backend systems on the flight deck. Commercial airplanes are involved in many complex systems designed so that both PF and PM can work together to maneuver the aircraft, communicate with air traffic controllers, and deal with emergency situations by cross-checking based on SOPs. Effective HCI is an important characteristic of improving operational safety in aviation. Understanding the relationship between human performance (of both PF and PM) and system designs (control inputs and HMI) would help aeronautical engineers develop human-centered systems for the future single-pilot operation (SPO) flight deck. Implementing touchscreen elements in the flight deck will help progress toward the SPO goal, allowing spatial flexibility in designing the flight deck. All levers, switches, and knobs could be arranged in a way that a single pilot can easily reach them. Furthermore, carrying out eye-tracking experiments during the design phase might help in reducing the pilot's head-down time while interacting with the touchscreen elements.

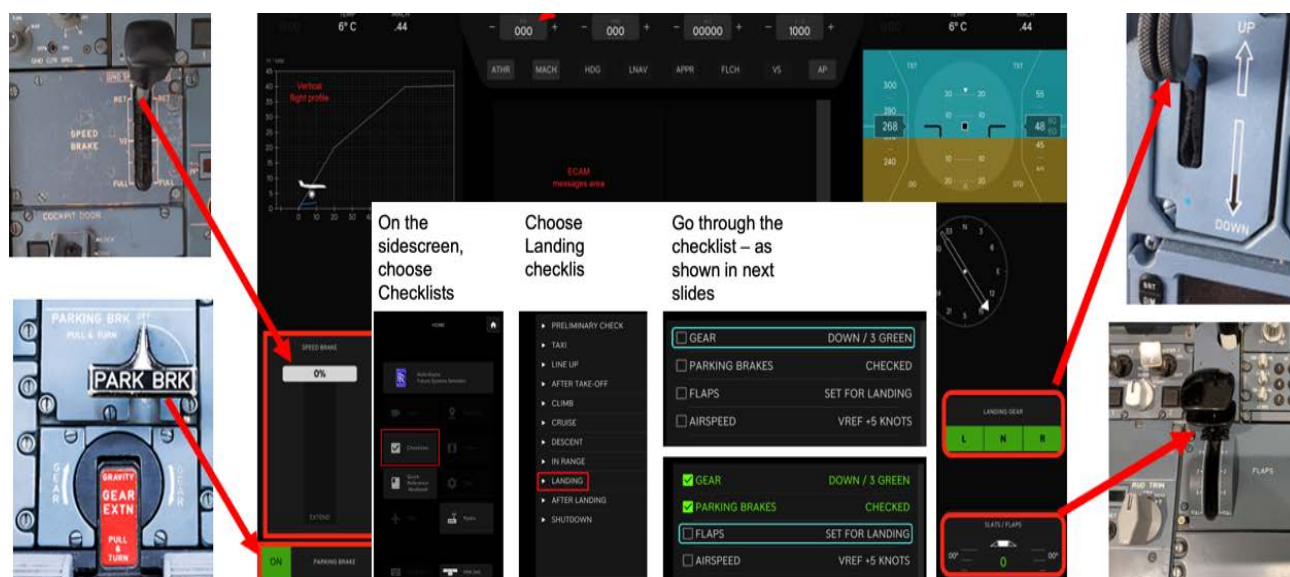


Figure 8 The comparison between traditional and innovative touchscreen-based levers/switches for speed brake/parking brake (left) and landing gear/flap lever (right), and touchscreen-based, interactive checklist used in Instrument Landing scenario (center). Interacting with the landing gear and flap lever buttons will open a widget with a slider for the respective lever, like that of the speed brake.

5.4 Limitations and future perspectives

The application of a touchscreen can integrate input and output in the same area for visual feedback [34]. While the touchscreen shows many promises, HCI challenges and characteristics of pilots' operational behaviors have to be taken into account in the design processes [4]. The

finding suggests that the touchscreen is not yet mature enough to be used as control input on the flight deck. In particular, the handling quality of the touchscreen may have significantly decreased under turbulence situations which may need further investigation and mitigation of the turbulent scenarios. Furthermore, there are some potential

limitations that should be taken into account in current research. The first limitation is the small sample size, which could have an impact on the effect sizes (η_p^2) in statistical analysis. From a statistical perspective, a larger sample is suggested. However, it is difficult to recruit enough qualified pilots wearing eye tracker in flight simulator for data collection. For example, similar eye-tracking studies focused on PFs and PMs, the sample sizes were 8, 12 and 14 participants respectively [35-37]. Therefore, the number of 12 participants in the current research was an acceptable number. The second limitation would be the difficulty of defining an AOI from an out-of-cockpit view due to FOV of eye tracker, which is one of the most common areas that pilots are fixating on the outside reference points (such as the centerline of a runway and precision approach path indicator).. Despite the fact that these limitations might have impacts on the contributions of current research, the innovative FSS touchscreen is an effective testbed for future flight deck design. Recently, there were some studies working on enhancing the usability and reducing the influence of turbulence for touchscreen, for example, folding touchscreen, braced finger for more stable interaction with touchscreen, providing visual and audio assistance, adding a graspable area for increased stabilization on touchscreen control inputs [3, 8, 10, 33].

VI. CONCLUSIONS

By analyzing pilots' objective visual behaviors and subjective ratings on the system usability of the touchscreen as control inputs, the findings on HCI related to future human-centered flight deck design would be applicable. There are some benefits to the implementation of a touchscreen for future flight deck design if the human-centered design principle can be integrated in the early stage. Furthermore, there are different requirements for PF and PM's tasks in the current two-seat flight deck, whereby the cognitive workload and the attention distributions on 'aviate, navigate and communicate' tasks between PF and PM are different, and PMs must conduct cross-checks with PF. The application of touchscreen flight controls may have the potential to facilitate single-pilot operations flight deck design in the future. HCI consideration must be consistent with human information processing on cross-monitoring and system integration to improve the usability of TSCs and pilots' operational characteristics on the flight deck. It is understandable that pilots preferred traditional flight deck levers/switches/knobs over touchscreens as control inputs due to safety concerns in hostile environments and familiarity. Furthermore, the practice effect had some bearing on the outcomes of current research, as PM had more opportunities to interact with touchscreens than PF. There is optimism that as research and technology develop, the drawbacks of the touchscreen will be mitigated so that it may be utilized more successfully with a plinth or handgrip around the touchscreens for finger stabilization in future flight decks.

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**Touchscreen controls for future flight deck design:
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