

Contrastive Analysis of Distractions to Pilot Caused by Various Flight Instrument Displays

Devinder Kumar Yadav^{1*}, Yingxue Zhao¹, Chunyi Gao¹, Yufei Wang¹, Tianzuo Dong¹,
Dinesh Bhatia²

¹University of Nottingham Ningbo, Ningbo, China

²University of Glasgow, Singapore, Singapore

Email: *dkharyanvi@outlook.com

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Abstract

Automation of aircraft instrument displays enhances flight safety, but it also increases complexity and pilot workload. Executing changes in flight plan, navigation or communication during flight using flight instrument switches often increases pilots' workload and this may also cause distraction that adds potential risks to flight safety. This study compares the conventional avionics panel and touchscreen avionic panel to find out the least distractive panel for the pilots. Thirty simulated flights using four different pilots were carried out; and aircraft speed, altitude and heading parameters using both avionics systems were observed to study the operational efficiency and pilot distraction resulted from each of the avionic systems. The distraction was examined by a parameter analysis based on the Mean Squared Error (MSE) mathematical model and visually by recording videos of each simulated flight. The results indicate that the touchscreen system is more efficient and less erroneous for the aircraft in maintaining the parameters as compared with the conventional system. There is also a clear relationship between task completion time and disruption level on the parameters control.

Keywords

Aviation, Touchscreen, Safety, Conventional, Cockpit, Simulate, Flight

1. Introduction

According to Federal Aviation Administration (FAA), approximately 60% - 80% of aircraft accidents occur due to human error as a result of fatigue, distraction and inappropriate decision making [1]. The researcher argues that the aviation industry initially pursued cockpit automation to improve aviation safety and re-

duce the workload of pilots, but aircraft automation eventually has become one of the main causes of aviation accidents. The automation has significantly decreased the flight accident though. Adjustment on flight plan, navigation and communication during flight often tend to divert pilots' attention from certain flight instruments, which may result in distraction. This may add potential risks to the normal flight operations.

Modern aircraft uses highly sophisticated automation equipment, such as Electronic Flight Information System (EFIS), Flight Management System (FMS), and Electronic Centralized Aircraft Monitoring (ECAM)/Engine Indicating and Crew Alerting System (EICAS). These systems use integrated avionics displays and their control panels are installed in cockpit of the aircraft. Two types of EFIS avionics control panels, the conventional switch operated panel and touchscreen panel are compared in this study by using a flight simulator to identify the most promising panel method. Therefore, many simulated flights using replica of Cessna 172S aircraft cockpit were planned and executed by four different pilots. Flying time for the flights was recorded from takeoff-point of the departure airport to overfly-point of the destination airport. The estimated duration of each flight was one hour, assuming that the aircraft is flying at 100 knot cruise speed. However, the actual duration of each flight was slightly varied, because the pilots manually controlled the aircraft. Basic flight parameters, such as the aircraft speed, altitude and heading for both the avionic control panel systems were compared to investigate the operational efficiency as well as the distraction to pilots resulted from the use of each system.

Consequently, the flight parameters were evaluated and graphically presented using MATLAB software in this project. Likewise, the distraction was examined by analysing the parameters using Mean Squared Error (MSE) mathematical model and the distraction was also observed visually by recording videos of each simulated flight. The results demonstrate that Garmin Touchscreen Navigator (GTN) system is more efficient and less erroneous for the aircraft in maintaining airspeed, altitude holding and heading control during flight as compared with Garmin 1000 (G1000) conventional EFIS system. It is also observed that depending on the system used (GTN or G1000), there is a clear relationship between task completion time and distraction level by each task on aircraft speed, altitude and heading control.

2. Avionics System Characteristics and Development History

Continuous advancement of aircraft systems, internet and engineering technology encourage further sophistication of integrated avionics in the aircraft controls and operating systems. According to [2], integrated aircraft avionics technology is different from traditional avionics system, which originally could be independent of the radar system, communication system, navigation, and positioning system. This technology is a kind of system that integrates microcomputer features into an aircraft avionics system. It is composed of one to two core processing units and several subordinate computing elements. Therefore, while

further improving the traditional avionics technology, it ensures that each link in an aircraft operation can perform their respective functions, smoothly.

According to [3], aircraft avionics systems have experienced a transformation process from independent-type to joint-type and then to advanced integration of the systems. Throughout the development of avionics system technology, the integration, generalization, and modularization have been the future development trends. Avionics system structure has been evolved in recent years due to computer and information technology development, in fact. Compared with transport aircraft, GA aircraft have a relatively low technical threshold, but along with meeting safety requirements, avionics design should also contribute to minimise the price tag of the aircraft. Therefore, an integrated avionics architecture generally aims at reducing the life cycle cost of the aircraft, simplification of the system application and improving its performance.

Modern avionics equipment are complex systems consisting of multiple sub-systems, interdisciplinary technology, multiple computation sections and several input signals. Consequently, new generation avionics system faces the challenges of achieving multi-functions, high quality, strong capability and a low cost of production. In addition to basic functions of avionics systems, such as flight and engine instrumentation, communications and navigation devices, some other functions can also be customised. The other functions may include, automatic pilot, flight management system (FMS), data-link communications, audio and visual warning systems, weather radar and collision avoidance system [2].

In view of the increasingly complex avionics system, integration technology has become one of the most concern in this field. Large-screen instrumentation displays may replace multiple independent displays and central processing computers as the core of the integrated avionics system. This is to reduce the number of avionics system equipment and improve reliability of the systems. Information acquisition, processing and display can be done centrally through a large-screen display (LSD), so that pilot can access the status of the on-board equipment through the LSD. This may reduce the workload of the pilot. When a LSD replaces multiple displays and central processing computers with independent functions, the display will no longer be just a display terminal, but it may also have the high-speed data transmission and processing capabilities. Functions that previously required hardware or complex mechanical operations can now be carried out by some software. Additionally, the software can make the information content display more vivid, flexible and extendable. It also saves space inside the fuselage and it contributes in reducing the weight and cost of the aircraft [3]. According to [2], the touchscreen-based control panels will gradually replace the traditional button-based control panels. In addition, voice command and control will be adopted in LSD-based avionics systems. Likewise, driven by application demand, it will be possible to add automatic warning and flight control functions to a GA aircraft too in future. Another advantage of LSD is being more conducive to an intuitive display of digital maps, satellite maps, three-dimensional terrain, and weather cloud maps with a strong intuitive information. It is helpful for pi-

lots to improve situational awareness, make predictions in advance that may enhance flight safety [2] [4].

3. Typical Products Used in Avionics Display

Since the G1000 system accounts for more than 70% of the integrated avionics system of medium and low-end GA aircraft, its system configuration and module functions are introduced and compared with related products [5]. GTN750, Entegra Release 9, and Chelton Flight System are also discussed in this study. An aircraft with a basic G1000 installation contains two LCD displays with a powerful integrated display-function that provides a wholly vitrified cockpit. Moreover, it is one of the most integrated avionics operating system in the world for GA aircraft. Consequently, some of the famous GA aircraft manufacturers, such as Diamond, Cessna and Beechcraft use G1000 avionics for their small aircraft as well as business jets [6]. Although it seems that G1000 has already become a popular avionics system, the GTN 750 is being hailed as a next multifunction avionics display system due to its simpler touchscreen operations. Likewise, the Entegra Release 9 as an integrated avionics system for light GA aircraft was launched in year 2003 [7]. According to the company, the architecture of the Entegra Release 9 is a full modular equipment, and it includes high-resolution IFD5000 displays, dual Air Data and Attitude Heading Reference Systems (ADAHRS), dual-redundant FMS900w systems with a QWERTY keypad, next-generation fully digital 16-watt VHF NAV/COM radios, and dual WAAS/RNP-capable GPS receivers. Furthermore, the Entegra Release 9 is a system designed to eliminate any unnecessary complexity, reduces head-down time, provides a new level of redundancy, and most importantly it improves flight safety.

According to [8], the GTN 750 navigator offers a complete GPS/NAV/COM-M/MFD capability in a single solution. Its centralized touchscreen provides an easy access to navigation, radio tuning and multifunction display features. Similarly, it also provides high-resolution terrain mapping, graphical flight planning, georeferenced charting, traffic target surveillance, multiple weather options, taxiway diagrams and a host of other advanced navigation features. Furthermore, the navigator can also integrate with other Garmin avionics, such as voice command and wireless cockpit connectivity to support data streaming. Consequently, an entire flight plan can be visualised including departures, arrivals, visual or instrument approaches, holding procedures, etc. Likewise, it can also overlay approach charts and potential hazards, such as terrain, weather and traffic on a dynamic moving map for enhanced situational awareness.

According to [9], the Chelton Flight System was initially founded in 1997 and it had developed the first FAA-certified synthetic vision flight display system. The main features include synthetic vision with three-dimensional highway-in-the-sky navigation, integrated flight management and hazard alerting, and ultra-compact highly ruggedized sensors. The researcher believes that these technologies provide enhanced safety, efficiency, and flexibility in operating envi-

ronment to users. Additionally, this system is approved for all kind of aircraft due to its uniquely customizable open-architecture systems. Consequently, it has been certified for more than 700 types of aircraft, so far.

4. Methodology

A standard flight route was designed using Seattle area VFR map for the simulated flight for a Cessna 172S aircraft using a flight simulator to carry out this study. The primary purpose of the simulated flights was to observe human factor issues, such as distraction, pilot fatigue, pilot response to various flight tasks while using the traditional switches-based instrument panel and touchscreen-operated panel. Four pilot students with similar flying skill level and simulation experience were selected to carry out the flights. As this is a preliminary study, no licensed pilot was used for carrying out the flights. However, the pilots who performed the flights were trained to private pilot skills standard in a flight simulator laboratory environment at a university. After familiarization of G1000 and GTN, each pilot carried out one G1000 and one GTN flight according to a pre-defined flight plan. A co-pilot was required to do routine flight tasks and to note down instructions and flight parameters, including the tasks completion time. Likewise, a laboratory based mock air-traffic controller was appointed to give instructions to pilots regarding the simulated air traffic routes.

Before carrying out the simulated flight, each pilot was given a learning period to become accustomed to the simulated environment and technical features of the represented aircraft. The period lasted for thirty minutes consistently for all the pilots, individually. The pilots were told that they would encounter variable wind conditions, but they were not informed about severity of the wind. After each run, the pilots were asked to comment on comparable operational difficulties, which they might have experienced in carrying out the flight tasks using the respective panel on their flights.

Pilots were briefed about flight plan and purpose of the simulated flights (**Figure 1**). During the briefing, they were told that they would carry out a simulated flight on a single engine Cessna 172S aircraft at 4000 feet from Skagit Regional airport (ICAO code KBVS) to Tacoma Narrows airport (ICAO code KTIW). According to the [10], civil airports are abbreviated by codes, which are given by International Air Transport Association (IATA) and the International Civil Aviation Organization (ICAO). In this paper, the ICAO codes are used. They are commonly used when navigating and preparing flight plans for civil aviation operations. Salient features of the flight plan were, flight distance of 79.8 Nautical Miles (NM), 307 feet/minute desired climb rate, two waypoints and a planned-change in flight plan enroute. Likewise, desired cruise speed and estimated flight time were 100 Kts and one hour, respectively. The aircraft was required to be flown manually and the pilots were also informed about lags in flight control responses caused by efficiency limitations of the simulator switches. Pilots were encouraged to ask for any clarifications during the pilot briefing task.



Figure 1. Flight plan route.

5. Flight Plan Details

A flight plan was prepared to collect data and to observe the difference in pilot behaviour. Pilot distraction when completing the tasks during a manual flight using G1000 and GTN control panels was monitored visually and also using video recording. It was assumed that the distraction would result in fluctuations of the flight parameters. The fluctuations were then monitored and recorded in this study to analyse the magnitude of the flight parameters' errors. According to the flight plan, the aircraft took off from KBVS airport and climbed to 4000 ft with a rate of climb of 307 feet/minute (Table 1). This flight level was maintained till the waypoint 2 and then the descend phase completed from waypoint 2 to waypoint 3 starting from 4000 ft and ending at 2500 ft with a descend rate of 167 feet/minute. Subsequently, the aircraft reached overhead of KTIW airport according to the schedule. Following flight tasks were given to the pilots to investigate their distraction when operating using G1000 and GTN, respectively:

- 1) At 5 NM to the waypoint 1, change COM frequency to 121.72.
- 2) At 30 NM to the waypoint 2, zoom in/out map to see Pierce County airport (ICAO* code KPLU).
- 3) At 25 NM to the waypoint 2, make a change in flight plan to change destination airport from KPLU to KTIW.
- 4) At 5 NM to the waypoint 2, change the COM frequency from 121.72 to 128.00. Descend to 2500 feet with a rate of descend of 200 feet/minute.
- 5) At 5 NM to the waypoint 3, change the COM frequency from 128.00 to 118.5.

Calculations for climb and descent rates:

Table 1. Flight plan.

Flight route	Airport name	Desired track (DTK)	Distance travelled	Airport elevation	Flight duration in minutes (from set course time)
Departure airport	Skagit Regional Airport. ICAO Code: KBVS	/	/	145 ft	/
Waypoint 1	Arlington Municipal Airport. ICAO Code: KAWO	135°	21.4 NM	142 ft	23
Waypoint 2	Seattle-Tacoma International Airport. ICAO Code: KSEA	173°	43.1 NM	432 ft	26
Original flight plan destination airport (Waypoint 3)	Pierce County Airport. ICAO Code: KPLU	114°	15.4 NM	538 ft	20
New destination airport caused by change in the flight plan after Waypoint 2	Tacoma Narrows Airport. ICAO Code: KTIW	209°	15.3 NM	295 ft	10

$$\text{climb/descent rate} = \frac{\text{vertical distance (feet)}}{\frac{\text{horizontal distance (nm)}}{\text{speed (knot)}} \times 60} \quad (1)$$

$$\text{climb rate} = \frac{4000 \times 100}{21.7 \times 60} = 307 \text{ feet/minute} \quad (2)$$

$$\text{descent rate} = \frac{1500 \times 100}{15 \times 60} = 167 \text{ feet/minute} \quad (3)$$

6. Weather and Payload Condition

Weather and payload condition were set to remain same during the entire flight mission to control variants. All flights were started at 1400 Hours local time and outside temperature (OAT) was kept at 19°C, atmospheric pressure at 29.92 inch and crosswind of 10 kts at 120 degrees. Likewise, the visibility was set at 8.69 NM, clear clouds from 0 - 2000 feet and from 4000 - 6000 feet altitudes while cirrus clouds were set from 2000 - 4000 feet. Similarly, the payload was set as 350 pounds, both fuel tanks filled at the full capacity and the centre of gravity as 0.

According to standard operating procedure for pre-flight equipment setting on conventional EFIS displays, the buttons need to be checked and confirmed that they function correctly. Similar actions are required on the setting-panel for navigate *To*, *Edit* and *Apply* functions. According to the flight plan, the required functions are to set-up and change flight plan, change COM frequency and adjusting the map. The detailed comparison for operations functions is listed in **Table 2** below.

7. Data Sample Size and Analysis

A total of 30 hours of simulated flights were carried out and the flight data were

Table 2. G1000 and GTN function comparison.

Functions	G1000 traditional switch operated EFIS	GTN touchscreen operated EFIS
Insert flight plan	Press FPL bottom, rotate knob to select alphabets for airport code, e.g., KBVS. Press ENT twice to confirm the airport, then rotate knob to select other waypoints.	Press Flight Plan box; press Add Waypoint, type in airport code, e.g., KBVS in keyboard. Press Enter to confirm the airport. Then add other waypoints.
Change flight plan	Rotate and press knob to select the desired airport to delete, press DEL and Press ENT to confirm deletion. Rotate knob to select alphabets for airport code, e.g., KBVS. Press ENT twice to confirm the airport.	Press the Waypoint Code box to delete desired airport, press Remove. Press Add Waypoint/Insert After/Insert Before, type in the desired airport code using keyboard, press Enter.
Change COM frequency	Rotate COM-knob to select standby frequency, then press exchange bottom to change COM-standby frequency to COM-frequency.	Press STBY and type in COM-Standby frequency using keyboard, press Enter, then press COM to change frequency.
Zooming of map	Rotate knob to zoom, push knob up/down to switch the map upward/downward.	Use pinch and twist gestures for zooming and rotating.

recorded and stored as text files using the inbuilt flight simulator software. Each pilot flown the flight-leg of one hour duration according to the flight plan using GTN and then repeated the leg using G1000 on a different day, but with the same weather conditions. Therefore, the flight duration for data collection for each pilot was two hours in total. During the flight duration, the five identical tasks were given to all the four pilots. As a result, the data recording was done for a total of eight hours of flight time. The remaining 22 hours were spent equally by the pilots for practice flights. Aircraft heading, altitude, and airspeed were observed as the most affected parameters when additional tasks were given to the pilots during the flights. Many parameters, such as airspeed, system pressure, flight control positions and inputs, thrust vectoring, angular moments, angle of attacks and side slips are generally recoded by the simulator during the flights [11]. However, only the primary flight parameters for heading, altitude, airspeed, and time were selected for this study. For mathematical modelling, the Mean Squared Error (MSE) for each given task in both G1000 and GTN simulation flight were calculated and compared. The MSE calculates the average squared difference between the standard values and the actual values. It is always positive and the experiment indicates that the closer the MSE values to zero, the better the pilot performance. Therefore, the error was amplified after the use of MSE calculation for effective observation. According to [12], the equations for the

MSE is:

$$\text{MSE} = \frac{1}{n} \sum_{i=1}^n (Y_i - \hat{Y}_i)^2 \quad (4)$$

where,

Y_i is actual value;

\hat{Y}_i is standard value.

The actual ground track (TRK) is the standard value \hat{Y}_i for heading. While executing the flight plan from KBVS to KAWO, the aircraft had experienced left-crosswind of 2 Knots. To keep DTK at 135 degrees, the TRK had to be adjusted to 134 degrees. From KAWO to KSEA, the aircraft had left-crosswind of 8 Knots. So, to keep DTK at 173 degrees, TRK had to be adjusted to 169 degrees. Likewise, from KSEA to KTIW, the aircraft had left-crosswind of 10 Knots. Therefore, to keep DTK at 209 degrees, TRK was adjusted to 204 degrees. The standard value \hat{Y}_i for speed was 100 Knots. Since it was difficult to control climb and/or descent rate that influences altitude parameters during a manual flight, only the altitude for cruise phase was evaluated. For the cruise phase, the standard value \hat{Y}_i was 4000 ft. The crosswind was introduced to bring more instability and distraction to pilots while operating the aircraft assuming that the pilots might tend to make large errors in flight parameters. This was done to achieve large denomination of the results. Moreover, in a real flight, pilots often experience different wind and weather conditions. By adding crosswind condition in simulated flights, the results became noticeable.

To examine the distraction to pilot during flight using G1000 and GTN, MSE values for flight heading, speed, and altitude as shown in **Tables 3(a)-(c)** are calculated using Equation (4). Similarly, the columns of **Tables 3(a)-(c)** show the MSE values calculated for each specified task according to the flight plan using G1000 and GTN. Due to the large errors made by the pilot 3 in maintaining the airspeed, the MSE error calculations could not provide any acceptable information about the airspeed. This is also reflected by the MATLAB plot (**Figure 7** for pilot 3 speed). So, it was ignored for the analysis, because the other three pilots' data have provided enough indication of the MSE trend. So, the final conclusion was made using a holistic approach on the basis of MSE trend of all the other flight parameters.

In order to evaluate the efficiency of G1000 and GTN during simulation flight, a task completion timetable had been developed showing the time spent in seconds by pilots for each given task using G1000 and GTN. The first column of **Table 4** shows the time taken for inserting the flight plan into G1000 and GTN systems and later columns of the table represent the time taken by pilots to finish each task using G1000 and GTN. Consequently, MSE ratio is obtained by dividing the MSE values of G1000 and MSE values of GTN. The ratio of greater than 1.0 indicates that the time taken using G1000 is greater than the GTN time. Subsequently, the MSE values for G1000 and GTN were compared for each participating pilot. It is observed that most MSE values for G1000 are greater than

Table 3. (a) Mean squared error for aircraft heading; (b) mean squared error for aircraft speed; (c) mean squared error for aircraft altitude.

		(a)					
		Task 1	Task 2	Task 3	Task 4	Task 5	Total
Pilot 1 Heading MSE (Degree²)	G1000	3.4872	11.467	4.6694	0.9306	2.5077	2
	GTN	0.3684	4.6297	2.2903	1.7124	2.6452	3
		Task 1	Task 2	Task 3	Task 4	Task 5	Total
Pilot 2 Heading MSE (Degree²)	G1000	17.0389	12.6921	8.6053	1.8897	1.0764	2
	GTN	12.4878	3.512	13.8043	33.0476	0.7169	3
		Task 1	Task 2	Task 3	Task 4	Task 5	Total
Pilot 3 Heading MSE (Degree²)	G1000	9.3283	182.5748	54.2388	60.0059	3.3737	0
	GTN	0.1104	5.1815	11.7683	0.8886	0.5651	5
		Task 1	Task 2	Task 3	Task 4	Task 5	Total
Pilot 4 Heading MSE (Degree²)	G1000	11.83	21.56	808.87	112.38	177.47	2
	GTN	30.92	53.21	3.39	5.39	10.00	3
		(b)					
		Task 1	Task 2	Task 3	Task 4	Task 5	Total
Pilot 1 Speed MSE (ktas²)	G1000	4.5162	29.3951	76.3827	169.407	65.8315	2
	GTN	41.9649	61.1317	63.0841	56.8702	0.7129	3
		Task 1	Task 2	Task 3	Task 4	Task 5	Total
Pilot 2 Speed MSE (ktas²)	G1000	135.2141	75.0932	190.065	38.0379	20.4589	2
	GTN	323.2039	11.6571	11.2445	10.9166	25.1926	3
		Task 1	Task 2	Task 3	Task 4	Task 5	Total
Pilot 3 Speed MSE (ktas²)	G1000	173.7089	60.0201	23.6235	72.8949	68.3729	4
	GTN	683.2469	376.4651	282.4448	139.4125	6.8849	1
		Task 1	Task 2	Task 3	Task 4	Task 5	Total
Pilot 4 Speed MSE (ktas²)	G1000	242.1014	1.2650	108.8021	161.8549	7.4416	1
	GTN	29.2433	59.3385	28.08	29.6916	2.1963	4

(c)

		Task 2	Task 3	Task 4	Total
Pilot 1 Altitude MSE (ft² msl)	G1000	5706.6902	2571.8692	1752.5217	0
	GTN	5689.6725	2410.0334	676.6967	3
		Task 2	Task 3	Task 4	Total
Pilot 2 Altitude MSE (ft² msl)	G1000	2499.7401	17,401.1899	1572.1048	1
	GTN	733.4821	669.6731	3860.7540	2
		Task 2	Task 3	Task 4	Total
Pilot 3 Altitude MSE (ft² msl)	G1000	10,168.2798	26,360.7757	3351.1370	2
	GTN	6061.3702	118,548.9198	9294.9474	1
		Task 2	Task 3	Task 4	Total
Pilot 4 Altitude MSE (ft² msl)	G1000	52,312.2781	72,418.7845	57,609.0838	0
	GTN	27,241.3726	5588.3937	3221.4320	3

Table 4. Time taken for each task.

		Insert flight plan	Task 1	Task 2	Task 3	Task 4	Task 5	Total
Pilot 1 Time (s)	G1000	72	23	65	55	27	17	0
	GTN	19	6	33	8	6	8	6
		Insert flight plan	Task 1	Task 2	Task 3	Task 4	Task 5	Total
Pilot 2 Time (s)	G1000	57	23	97	35	29	20	1
	GTN	25	11	39	49	8	4	5
		Insert flight plan	Task 1	Task 2	Task 3	Task 4	Task 5	Total
Pilot 3 Time (s)	G1000	65	72	60	44	38	19	0
	GTN	20	10	33	18	13	9	6
		Insert flight plan	Task 1	Task 2	Task 3	Task 4	Task 5	Total
Pilot 4 Time (s)	G1000	78	30	40	133	50	28	0
	GTN	22	7	3	21	6	11	6

that of GTN (**Tables 3(a)-(c)**). Likewise, the time duration ratio (TDR) is calculated by dividing the time taken for completing each specified task using G1000 and GTN (**Table 4**). The observation from **Table 4** leads to a conclusion that a task completion time using GTN is less than G1000.

8. Results and Discussion

A frequent distraction caused by aircraft instrumentation to a flight crew may increase fatigue to the crew leading to the aircraft operators assigning more resources to manage fatigue related risks. Likewise, the distraction may also affect situational awareness of the pilot. According to [13], pilots direct their attention to flying the aircraft that requires an awareness of the flight state and the aircraft automation state. They also pay attention to technical operations of the aircraft, functioning of other flight crews, air traffic and weather conditions. Thus, in addition to ongoing allocation of resources to address hazards and risks as a result of operational fatigue, some form of fatigue management training will also be required. Furthermore, the operators need to identify and assess potential fatigue hazards and risks, carry out fatigue monitoring underpinned by ongoing data collection and analysis, assess the effectiveness of the fatigue mitigation strategies, and develop a fatigue risk management system [14]. Subsequently, the cost of flight operations will increase. According to observations during the data collection, it was found that more the time spent by the pilots in handling the flight instruments or displays for making flight plan changes or by distraction, more the fatigue had occurred. Though this statement might become more conclusive, if the data could be collected on a longer flight durations. While technology enhancements can deliver the proverbial “pot of gold” at the end of the rainbow, but they rarely do without careful considerations [15]. The researcher has demonstrated this through a graphical presentation (**Figure 2**).

Various bar charts are developed to further analyse the differences in flight parameters using the collected data. The higher the bar, the greater the error as indicated by **Figure 3**. That means the difference between the desired value and actual values of the heading, altitude and airspeed vary, significantly. Therefore, the task 2 of the pilot 3 has the highest bar as compared with rest of his task bars, which implies that the pilot 3 made a large error during the flight task 2 (**Figure 3**).

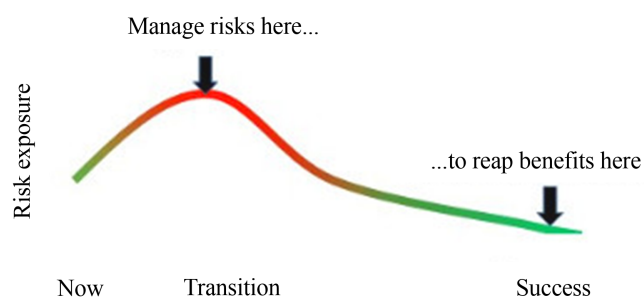


Figure 2. Methodology for managing flight risks.

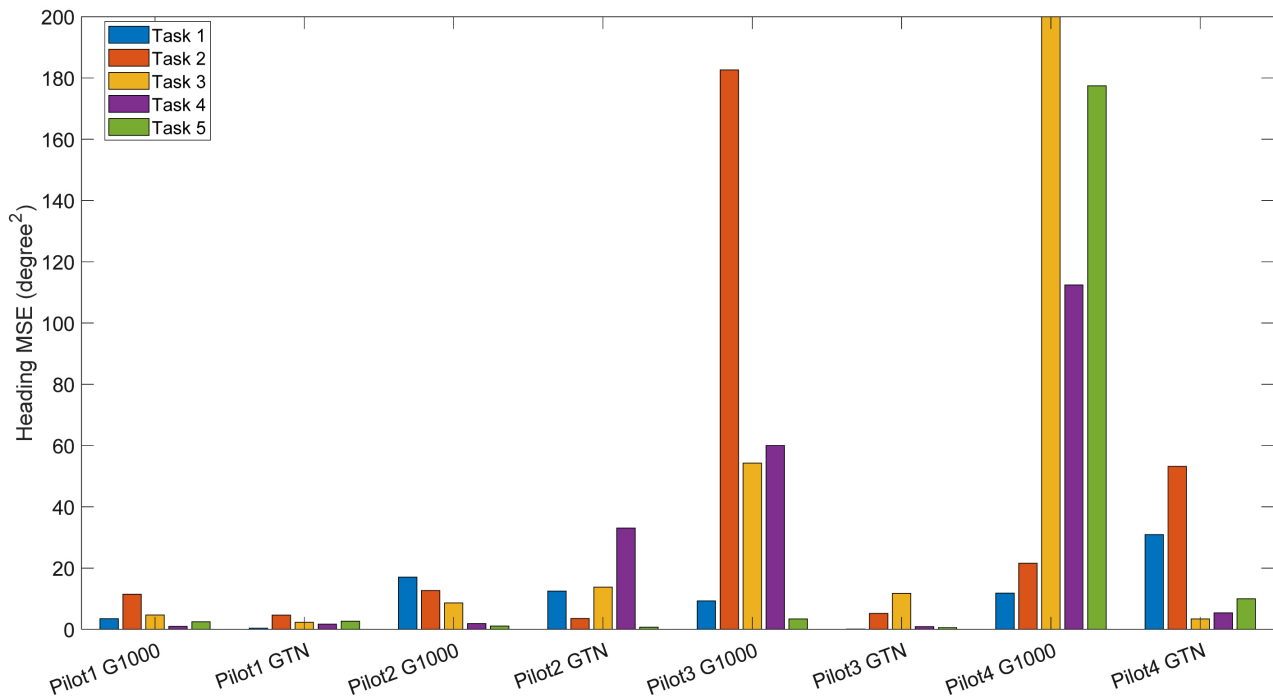


Figure 3. MSE heading comparisons of G1000 and GTN.

Hence, it can be concluded that higher the MSE value, more distraction the pilot experienced in the flight. This leads to more fluctuations in the aircraft heading parameters or more off-the-track errors have occurred. Furthermore, the MSE value of G1000 is generally higher than the GTN value for most tasks done by the pilots. For example, the MSE value of G1000 for the Task 2 is more than twice the value of GTN for the Pilot 2. Therefore, the pilots using GTN for the flying tasks have less error in heading than using G1000. This indicates that GTN tends to have less influence on pilot's operational efficiencies in heading-control compared with G1000.

From **Figure 4**, it can be comprehended that the MSE values for airspeed is larger than that for heading, because the pilots experienced that the airspeed was more difficult to maintain to a constant value as compared to headings. Correspondingly, the MSE value for airspeed is also higher for G1000 than GTN. For example, for pilot 3 doing the Task 1 using G1000, the value is approximately three times to the GTN value. Therefore, the influence of the GTN distraction on pilot behaviour in speed control is much smaller than that of the G1000. This is consistent with the conclusion drawn from analysis of the MSE heading.

Figure 5 ascertains that the MSE altitude value for G1000 is generally higher than the GTN for most tasks carried out by the pilots. For example, the MSE altitude value is about eight times for G1000 than the GTN value for the task 3 performed by the pilot 4. Therefore, the data of MSE altitude indicate that the distraction and influence on pilot behaviour in altitude control caused by GTN is less than that of G1000 system.

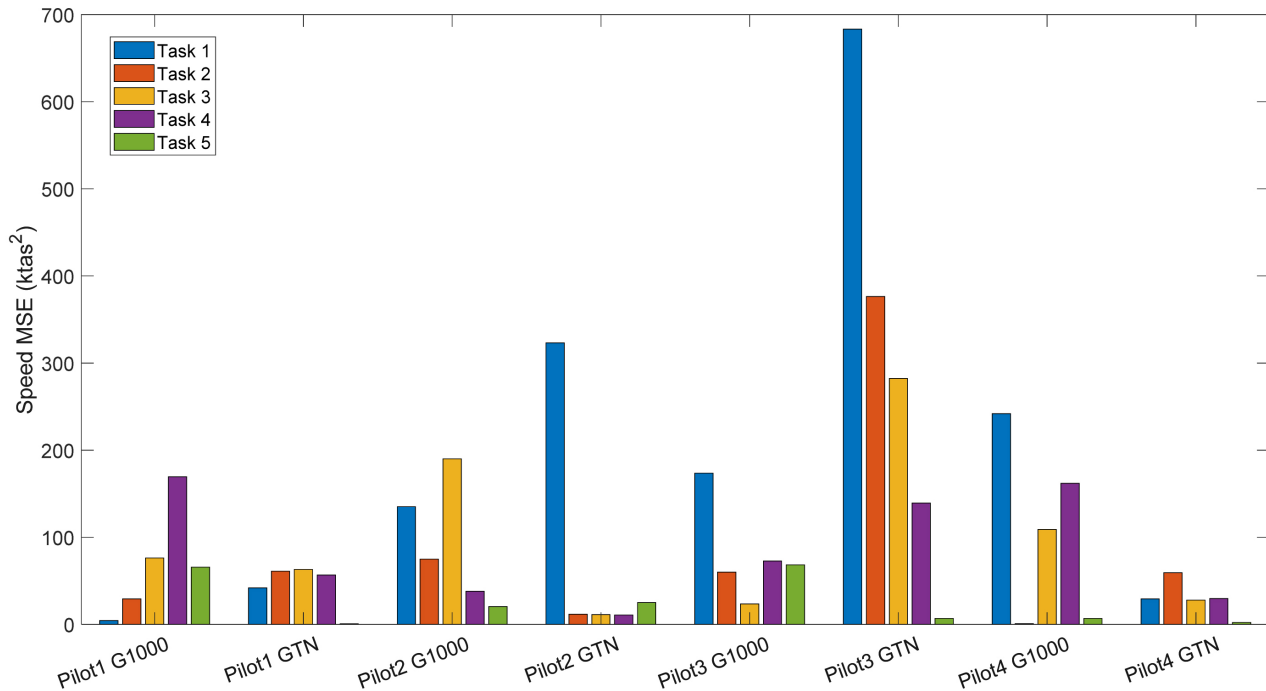


Figure 4. MSE speed comparisons of G1000 and GTN.

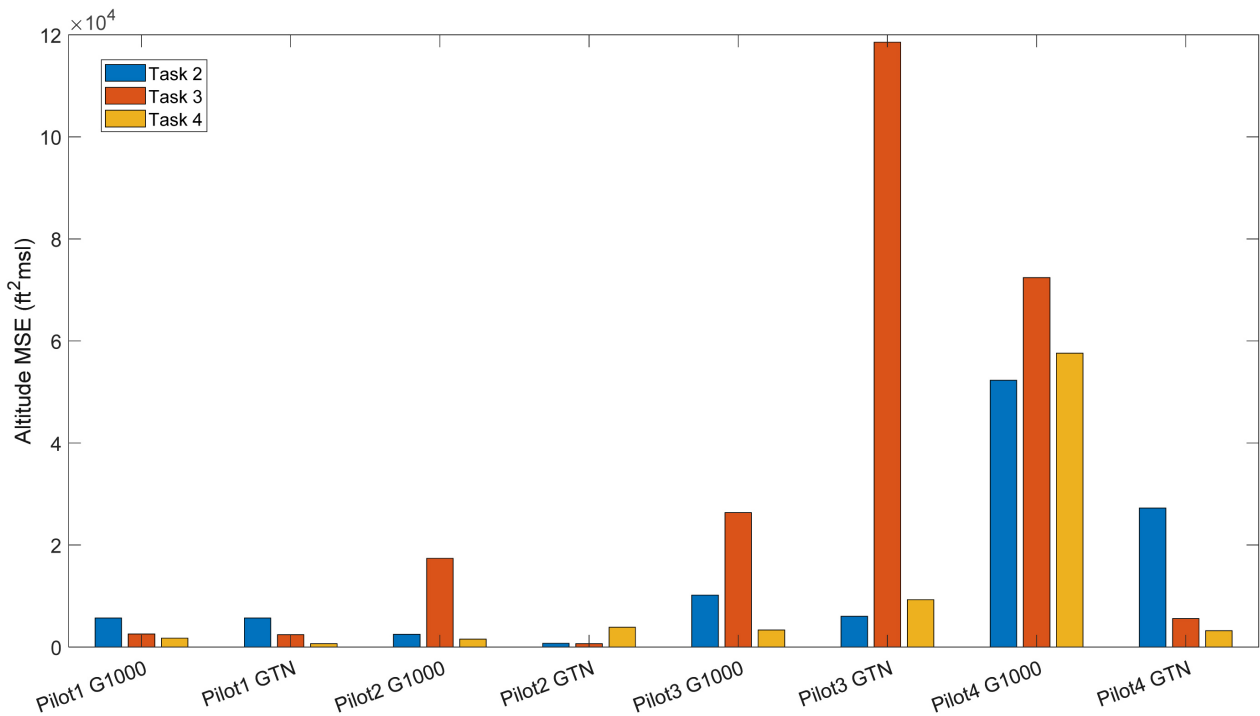


Figure 5. MSE altitude comparisons of G1000 and GTN.

Likewise, the average time taken by the pilots to operate G1000 is around four times than the time for GTN (Figure 6). This shows that the pilot efficiency when using GTN is significantly greater than that of using G1000. Similarly, there is a clear relationship between task completion time and the MSE values.

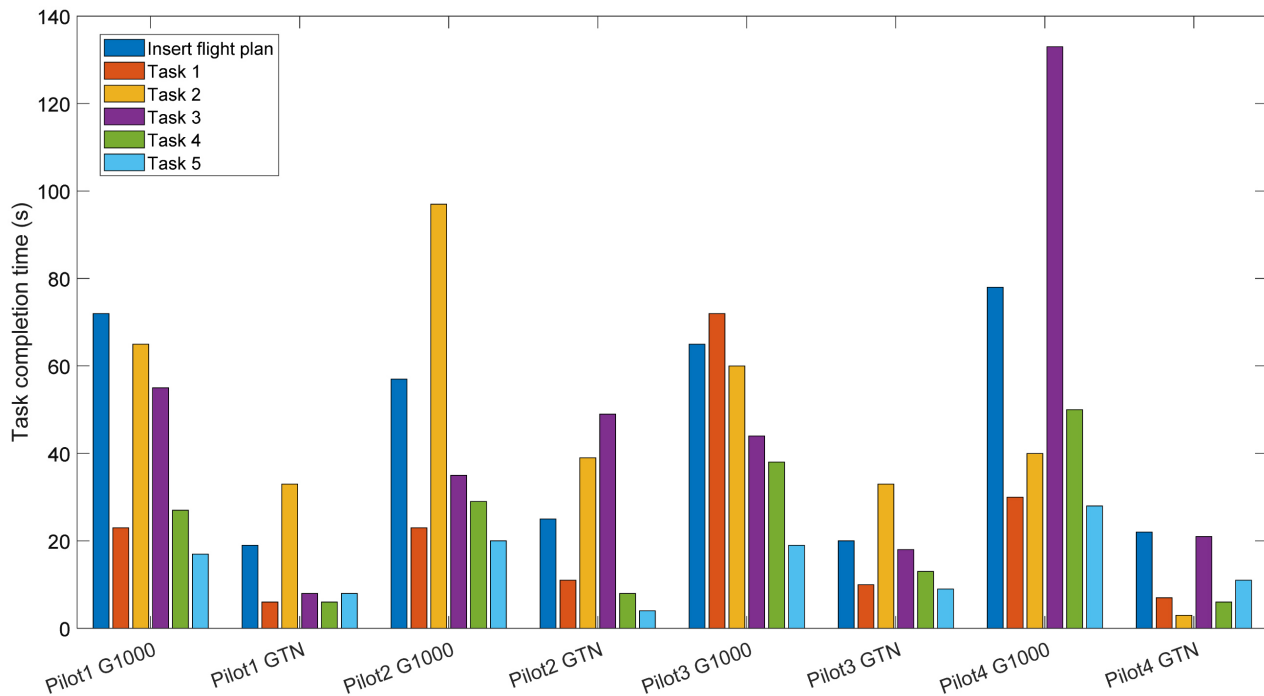


Figure 6. Task completion time comparisons of G1000 and GTN.

So, lower the MSE value and shorter task completion time, the less distraction caused to the pilots.

Meanwhile, for further validation, the MATLAB plotting for each heading, airspeed and altitude with respect to the flight time for all the pilots has also been done for both G1000 and GTN (**Figure 7**). In the MATLAB plots shown by **Figure 7**, the y axis is the magnetic heading (HDG-mag) in degrees, the true airspeed (ktas) in knots and the aircraft altitude (alt) in feet mean sea level (ftmsl). Similarly, the x axis is the flight time shown by the timer and the vertical lines represent the start and end time of each task as mentioned in the flight plan. According to the plots, it can be perceived that there are different levels of fluctuation of flight parameters during each given flight task. Moreover, for GTN, less flight parameter fluctuations are noticed as compared to G1000 throughout the flight. The fluctuations may have correlation with the distraction to pilot caused by the use of different operating systems. However, the level of disturbance could not be evaluated effectively by the graphical method. That is why the numerical evaluation was done as a part of this study. As a result, this study leads to believe that the GTN touchscreen system is more efficient and less erroneous for the aircraft in maintaining the flight parameters as compared with the G1000 conventional EFIS system.

Finally, this research demonstrates that the conventional EFIS systems causes more parameter fluctuations and pilot distraction as compared to the touchscreen operated systems. However, it was not clear that what type of task using which kind of EFIS system cause more fatigue than the other. According to [14], fatigue hazards must be identified and mitigated against for each operation.

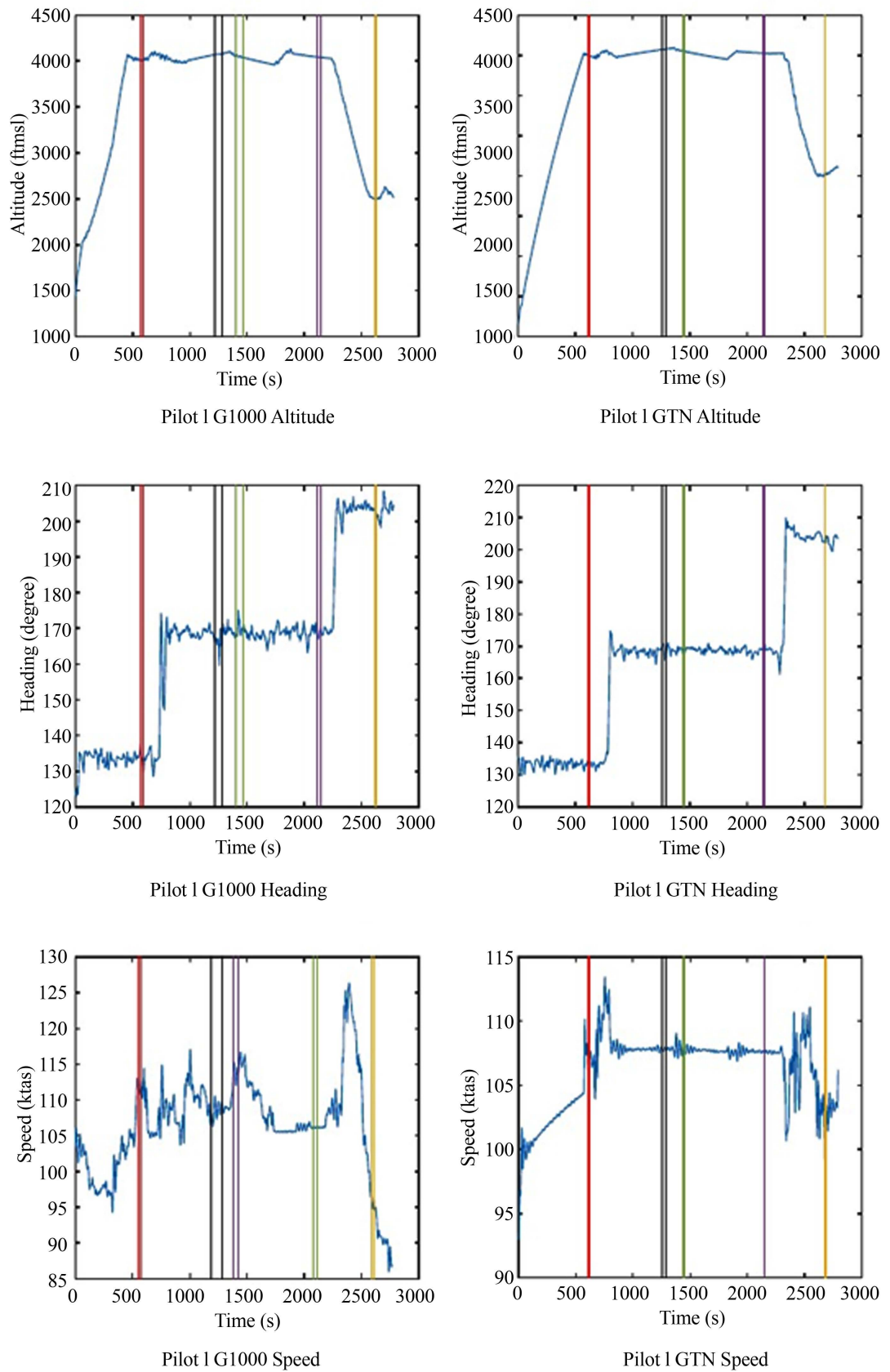


Figure 7. MATLAB graphs of flight parameters.

Furthermore, a fatigue risk management system (FRMS) cannot be used to generate one broad template for all aspects of a varied flight operations. For example, an operator with a mixture of aerial work, charter and training flights would not be able to establish one generic procedure to cover all operations under a FRMS. As each fatigue hazard of each aspect of each task will need to be identified, risk assessed and mitigated, the FRMS processes would likely to identify different fatigue level for the different types of tasks. The [14] further states that even within a category of flight operations, the level may vary. For example, a pilot would have different fatigue hazards in aerial photography as compared to power-line stringing. Consequently, a multidimensional management system to address the different fatigue risks of the different activities will be required to establish. Therefore, it is important to choose an appropriate EFIS display system to reduce pilot distraction and fatigue.

9. Error Analysis and Technical Limitations of This Study

This preliminary study did not use any licensed pilot to carry out the flights. However, the pilot students who performed the flights were trained to private pilot skills standard in a flight simulator laboratory. Therefore, due the laboratory conditions, the sample size was small. Likewise, the experiment was carried out using almost ideal weather conditions except some light crosswinds. Therefore, a larger sample size with various weather conditions using licensed commercial pilots to carry out the flights would be necessary to establish the findings of this study at the aviation industry level.

While observing the pilots' behaviour during simulated experiments, some technical and human factor issues that might had affected the fluctuations were also noticed. Firstly, due to a slow response of rotary knob of the G1000 system, pilots may rotate too many times that results in excessive adjustments in editing flight plans or changing COM settings. Secondly, the complex operations of the GTN touchscreen system as compared to the traditional system might have resulted in psychological pressure on the pilots. The pilots also reported that when operating GTN, they inadvertently touched the virtual buttons due to high sensitivity of the touchscreen and complex arrangement of the buttons on the screen. Finally, the pilots believed that it takes more time to execute a task using G1000 knobs as compared to GTN touchscreen based virtual buttons.

10. Conclusions

Aviation safety is a subject of immense concern in globalised aviation industry and crowded airspace. The most convenient and efficient avionic system is instrumental in reducing pilot workload related stresses during flight as well as in decreasing flight accident rate caused by human errors.

A couple of EFIS systems were compared to evaluate which system is the least distracting to a pilot. A total of 30 hours of simulated flights were conducted to investigate the fluctuations in flight parameters caused by the distraction. Pri-

marily, the aircraft heading, airspeed and altitude were monitored. The MSE values for the parameters were calculated analytically and examined using MATLAB. To evaluate the relationship between task completion time and distraction levels in the simulated flights, a task completion timetable was developed showing the time spent in seconds by the pilots for each given task using each display system. A relationship between time taken to do the task and MSE values has been found. The relationship shows that more time taken to carry out a task leads to higher MSE values.

Therefore, it appears that a touchscreen-based avionic system is relatively more efficient and causes less distraction to pilots during a flight as compared to a conventional EFIS system. Additionally, it is also found that a faster response and convenience of inserting flight plan, adjusting waypoints and using maps are the main advantages of a touchscreen system over a conventional system.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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