

Investigating Pilots' Operational Behaviours While Interacting with Different Types of Inceptors

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Abstract. There are different designs of inceptors applied in the modern flight deck. How do pilots define how to precisely control the aircraft as their intention? The main factors of flying quality investigations are carried out with the feel system characteristics and controlled element gain coefficient which is selected according to the pilot's opinion. The way of controlling things and their evolution has been with the humanity from the very beginning. This study compares pilot's behaviour while using three different methods to control an aircraft including traditional inceptor, gamepad and touchscreen control system in the flight simulator. It is to identify the best control mode that can be proposed to the aviation industry. Participants will use flight simulator interacting with three different control inputs, then provide their feedback using System Usability Scale. The results and descriptive statistics analysis are discussed based on touchscreen and HCI design on inceptors in the flight deck.

Keywords: Control Inputs · Flight Deck Design · Human-Computer Interactions · System Usability · Touchscreen · Inceptors

1 Introduction

1.1 Handling Qualities and assessment

Handling Qualities (HQ) have been in development since first aircraft has come to existence, especially from 1970s [11]. It is a never-ending process of proposing, testing and optimising at every stage, from control devices through the technology (e.g. Fly By Wire, FBW), up to the control surfaces (e.g. ailerons, elevator, rudder) and pilot's neuromuscular responses [1–3, 12]. During the development and analysis of existing and new aircraft technologies, HQ should not only be

assessed by mathematical analysis, but also through pilot's feedback and commentary, according to Cooper and Harper [6]. There are several ways for the test pilot to assess the experience, for example System Usability Scale (SUS) [9, 10], which was used in this research.

1.2 Inceptors

On the contrary to Handling Qualities, inceptors haven't involved much throughout of the history. It started with the Wright Brothers' airplane, which was using a stick and a cradle to control the pitch, roll and yaw of their Flyer I [16]. Shortly after that, the hip cradle evolved into the rudder pedals, through the "rudder bar" (pre-1919) [8]. After several dozen years, some of the aircraft companies decided to replace the central stick/yoke with a sidestick [13]. All of the above were subjected to thorough research and evaluations. Most of the studies focused only on comparing existing inceptors (e.g. sidestick vs central yoke). Experimental research done by Efremov et. al has shown that type of the inceptor is one of the variables in the pilot-vehicle system and its parameters like position (central/side), displacement/force, stiffness and damping can influence pilot's performance. Another point noticed was that using the side stick there was an increase in time delay in lateral channel movement scenario (pitch tracking task) as compared to longitudinal channel (roll tracking task). It has also proven that there is a decrease in pilot's phase delay and variance of error and decrease of the response delay between Force Sensing Control and Displacement Sensing Control. [4, 5, 17]

1.3 Aims

Aircraft becomes more and more automatic, with pilot's role changing, as they only needed to set and adjust flight parameters - there's less need for a sidestick or a central yoke as it becomes unnecessary weight. There's been research about designing a control system that helps pilots with limited experience to fly safely [14]. This shows that there is a need to explore different means of control, which would increase the learnability and safety. The aim of this research is to test a feasibility of designing a new control inceptor, which could lead to replacement of the current conventional sidesticks and central yokes, as suggested in author's previous works [7]. In order to link previous research with new touchscreen-based inceptor proposition, the following hypotheses can be formed: H_1 : "There is a significant difference on pilot's feedback on system usability among three control inputs" and H_2 : "There is a significant difference on pilot's variance of error among three control inputs".

2 Method

The data was gathered using a 'Pilot in study' method. Ten licensed pilots were invited to participate in a flight simulator experiment involving handling different types of aircraft control inceptors.

2.1 Participants

Ten participants holding a valid piloting license, aged from 24 to 63 ($M = 39.60$, $SD = 12.19$) with fixed-wing total flight hours experience ranging from 800 to 13300 ($M = 5810$, $SD = 3847$) took part in this research. Majority of them have an airliner-type rating (Airbus A320 family or Boeing B737-400/B747-400) and 8 of them were aviation instructors. Appropriate research approval was acquired from Cranfield University's Research Ethics System. All collected data is only available to the research team and were stored in accordance to the University's Ethical Code and the Data Protection Act.

2.2 Environment

The trials are conducted in an engineering flight simulator called Future Systems Simulator, shown in Fig. 1. It was developed by Cranfield University and Rolls-Royce in order to test various aerospace technologies, from the engine systems to Human-Machine Interface (HMI). For the purpose of this research, it was modified to accustom the trials involving different inceptors. Tests were conducted using an aircraft model of a generic long-range business jet based on Gulfstream G550. The model was developed by Dynamics, Simulation and Control Group at Cranfield University.



Fig. 1. Future Systems Simulator, Cranfield University, UK.

2.3 Trial procedure

Each participant had to fill in a demographic questionnaire, followed by a video briefing explaining the aims and objectives of the study. After that they were

seated in the flight simulator cockpit and shown the inceptor briefing. The order of inceptors was randomised. For each inceptor, the pilot had been given 1 minute of a test flight to get accustomed to the inceptor and aircraft dynamics. Four tasks followed after that, described in subsection 2.5. After completing the tasks, they were given a SUS questionnaire. When they tested the three inceptors, they were given a final feedback questionnaire to fill in. The trial procedure is shown in Fig. 2.

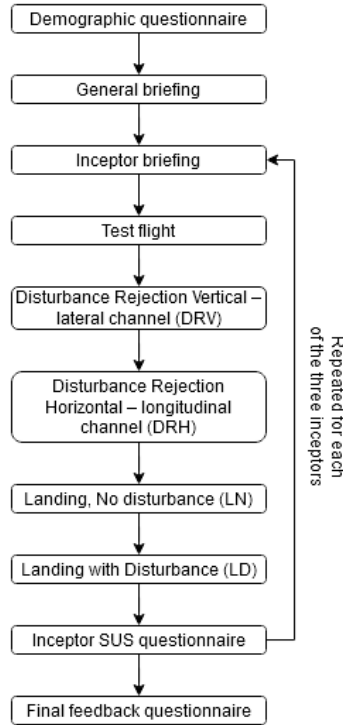


Fig. 2. Diagram showing the trial procedure.

2.4 Inceptors

The study uses three different inceptors:

Sidestick: The default FSS controller is sidestick, shown in Fig. 3. It is a passive displacement sidestick with a custom-made handle, mounted on a base of Thrustmaster HOTAS WARTHOGTM. Passive sidesticks are used in Airbus A320, among other aircraft and the total number of passive sidesticks in aircraft have increased significantly in the period of 2007 to 2017. [15].

Gamepad: Xbox gamepad controller was chosen to investigate how pilots with different backgrounds in using the gamepad for video games will behave and how fast they can adapt unusual way to control the aircraft. Participants were asked to hold the controller in both hands but only use their right thumb to move the right stick, while resting both hands on the extendable tray in front of them, as presented in Fig. 4.

Touchscreen: The touchscreen controller is a modified mobile touchscreen displacement stick. It is located in the centre of PFD, as shown in Fig. 5. The Y-axis is reversed. In the current state, the aircraft goes in the direction pointed by the subject. Participants were asked to use their right index finger to interact with the inceptor.

None of the controller types is an active inceptor, meaning it does not give any tactile feedback to the pilots.

2.5 Tasks

For tasks were developed for the purpose of this study - two main scenarios, each divided into two sub-scenarios:

Disturbance Rejection Task - (1) Vertical / (2) Horizontal Axis: Depending on the axis, the pilot was required to (1) keep the flight path vector indicator on the horizon line of the attitude indicator (Vertical Axis) or (2) keep the roll indicator on the centre position of the indicator (Horizontal Axis). The task started with 5 seconds of no disturbance, then the disturbance signal was injected in the inceptor signal for 45 seconds, followed by 10 seconds for a cooldown. For each of the sub-scenarios, the other control channel was disabled, so the pilot was only able to move up and down or left and right, for respective vertical/horizontal tasks.

Landing Task - (1) Without Disturbance / (2) With Disturbance: The pilot was required to perform a landing. The starting position of the aircraft was 5 miles away and in 54.5 degree offset angle to the runway. Initial speed was 150 knots (0.25 Mach), altitude was 1400 ft and heading was 90 degrees. Desired glide slope was 3 degrees. (1) First sub-scenario did not have any disturbance. (2) In the second sub-scenario, 5 seconds after start, the disturbance was introduced to both inceptor channels - vertical and horizontal and it lasted for 90 seconds. This is how long it took for the aircraft to reach the runway.

For all types of tasks, weather conditions were clear and there was no wind (only simulated turbulence as a disturbance). There was no other air or airport traffic. The disturbance tasks were chosen to familiarise the pilot with control in only one channel, and then to put both channels to the test in a landing scenario (easier and harder - without and with added disturbance). The disturbance signal



Fig. 3. FSS Sidestick.



Fig. 4. Xbox gamepad.

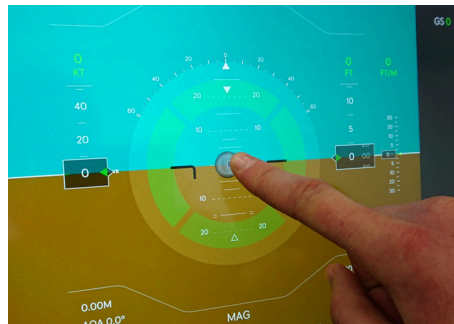


Fig. 5. Touchscreen controller.

was pre-generated before using a sum-of-sines forcing function. The disturbance signal is different for each task, but it is consistent between participants.

The following data was collected from each session: Demographics, experience with piloting aircraft and attitude towards introduction of touchscreen technology in aircraft; Pilot's control input - raw and with added disturbance; Flight simulation data - aircraft aerodynamics.

This study focuses only on control surface inceptors, so throttle, landing gear, flaps, spoilers, brakes and autopilot control were automated to minimise pilot's distraction. Participants were told to minimise usage of the rudder pedals while in flight.

3 Results and Analysis

Preliminary data recorded by the authors before the trials have shown differences in root mean square (RMS) error in sidestick and touchscreen controller deflection and performance in keeping the disturbance rejection task's target. Interestingly, sidestick and gamepad results had similar RMS error value. Results from first two participants had to be rejected, as after their session some elements were revised: the objective of Disturbance Rejection Vertical task was changed from keeping aircraft's pitch attitude to flight path vector on the horizon line and due to technical difficulties the side of the cockpit on which the pilots were seated was moved from left to right.

One-way ANOVA was computed to assess the system usability of three types of control and two Disturbance Rejection tasks. The response variables were Usability scores, rated by participants and variance of error of the task objective. The results and descriptive statistics analysis were discussed based on touchscreen and HCI design on inceptors in the flight deck. The assumption of sphericity was verified using Mauchly's test, and the Bonferroni was applied to perform pairwise comparisons after a significant overall test. Effect size of factors and interactions were quantified by partial eta square (η^2). Because of small sample size, 2-way ANOVA analysis did not show significant results.

The results have shown that there is a significant difference among three inceptors among all SUS features - Usability, Learnability and Total Scores. Most significant scores can be found in SUS Usability and Total score for DRV, and SUS Total score for DRH ($p < .01$). SUS Usability and Total Score for DRH and SUS Learnability for both tasks have shown smaller p-value, but still significant ($p < .05$). RMS error value have shown no significant difference among the inceptors for both tasks ($p > .05$). Pilots have ranked Sidestick as highest Usability controller, followed by gamepad and touchscreen. The main reason of this is the familiarity - they already had previous experience with sidestick. Gamepad results were lower than those of sidestick, but there is much bigger SD - this is because some pilots already experienced using this type of controller in video games. Touchscreen inceptor scored the lowest because none of the participants have experienced this type of controller in the past. Full scores from the ANOVA test can be found in Tab. 1.

Table 1. 1-way ANOVA summary. SS - sidestick; GP - gamepad; TS - touchscreen; M - Mean; U - Usability; L - Learnability

DRV/DRH	SS M(SD)	GP M(SD)	TS M(SD)	F	p	η_p^2
SUS U DRV	58.75(14.08)	44.89(29.53)	26.56(17.93)	7.32	.007	.51
SUS U DRH	60.31(14.85)	45.46(27.81)	34.06(19.13)	4.80	.03	.41
SUS L DRV	17.50(2.99)	12.97(7.55)	12.19(6.33)	4.85	.03	.41
SUS L DRH	18.13(2.22)	12.92(7.65)	11.88(6.51)	5.78	.03	.41
SUS total DRV	76.25(15.92)	60.63(32.83)	38.75(22.87)	9.42	.003	.57
SUS total DRH	78.44(16.42)	61.25(30.68)	45.94(25.00)	6.11	.01	.47
RMS DRV	2.31(1.15)	8.41(19.84)	5.03(2.27)	.56	.48	.07
RMS DRH	2.62(.52)	8.68(19.73)	2.89(.57)	.72	.43	.09

The trials have shown that, throughout the experiment, pilots would give highest SUS scores for the sidestick, however according to findings of Mclellan et al., users tend to put 15-16% higher scores for systems they already know [10]. With that in mind, it can be assumed that the scores for gamepad and touchscreen would be greater if participants had previous experience with them. It can also be seen in the case of gamepad - two of the pilots who had previous experience in playing video games using gamepad (around 50%-75% of time spent playing) gave a total SUS score much higher than average: 92.5 / 71.25 total score from those pilots in average between all four tasks, when the mean score for gamepad SUS total score was 59.

Since there were no previous known research involving replacement physical sidestick with touchscreen controller it can be assumed that the scores would be 15% higher if pilots had had more experience with piloting the aircraft using the touchscreen controller.

SUS analysis has also shown that Disturbance Rejection - Vertical axis task was easiest to perform (with mean SUS Total score across the participants of 45.94 (SD=29.35) for touchscreen, 67.19 (SD=37.03) for gamepad and 78.44 (SD=36.10) for sidestick), while the hardest one was the landing task with disturbance (with mean SUS Total score of 20.94 (SD=19.44) for touchscreen, 48.75 (SD=33.77) for gamepad and 66.88 (SD=32.51) for sidestick). Boxplots showing the distribution of SUS results can be seen in Fig. 6 for Usability, 7 for Learnability and 8 for Total Score.

There's also a tendency in significantly higher SUS scores among pilots who indicated an interest in touchscreen technology being introduced in aircraft cockpits - 40.00 (SD=10.51) for people who liked the idea and 26.46 (SD=23.51) for people who did not.

It can be seen that for the majority of participants, learnability for all three inceptors, especially for Disturbance Rejection tasks, was at least satisfactory. Landing tasks, being more challenging, especially using the novel touchscreen controller, was somehow lower than the rest. Interestingly, the learnability for gamepad was high, especially for subjects with previous gaming experience.

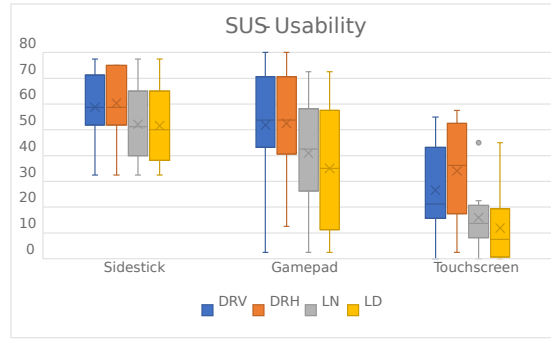


Fig. 6. System Usability Scale - Usability.

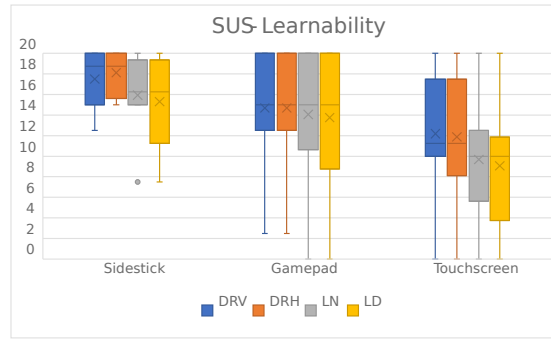


Fig. 7. System Usability Scale - Learnability.

Randomising the order of the inceptors did not have a significant change in pilots' behaviour: SUS score for gamepad was slightly higher (4.5 points on average) than sidestick from participants with sidestick as a first inceptor, however participants who tested gamepad and touchscreen first had the same trend for scoring: sidestick > gamepad > touchscreen. An interesting observation can be made here: in Disturbance Rejection tasks, the Root Mean Square error was lower for gamepad than sidestick across all the participants, which means that they performed the best using the gamepad (and they did not realise that, because it is on the contrary to majority of the SUS scores). The RMS values can be found in Tab. 2 and the distribution between subject is shown in Fig. 9.

Interesting point was raised by one of the participant, who said that landing tasks were easier for him using gamepad, which is reflected in SUS Usability score being higher by 3 points for both landings and his after-trial inceptor preference choice of gamepad. It is worth to note that according to their demographic questionnaire he has never or hardly ever played video games nor used this type of controller.

Analysis of the results has shown that the hypothesis H_1 : "There is a significant difference on pilot's feedback on system usability among three control

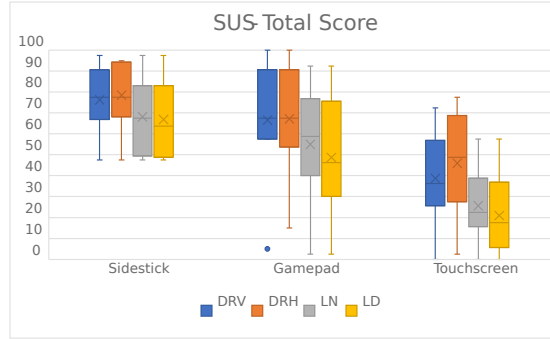


Fig. 8. System Usability Scale - Total Score.

Table 2. Root Mean Square of error (deviation from the task objective) averaged across all pilots for Disturbance Rejection Vertical (DRV) and Disturbance Rejection Horizontal (DRH).

	Sidestick		Gamepad		Touchscreen	
	Mean	SD	Mean	SD	Mean	SD
DRV	2.19	1.28	1.41	0.40	4.87	2.18
DRH	2.49	0.98	1.65	0.22	2.88	0.54

inputs” can be applied for comparison of sidestick with touchscreen and gamepad with touchscreen, however comparison of SUS scores from sidestick and gamepad have not shown significant differences. Hypothesis H_2 : ”There is a significant difference on pilot’s variance of error among three control inputs” is true for comparing the Disturbance Rejection Vertical task results among the three studied inceptors (RMS Mean equal to 2.19, 1.41 and 4.87, respectively for sidestick, gamepad and touchscreen), however RMS error Mean from Disturbance Rejection Horizontal task has shown that gamepad was more accurate inceptor than the rest (RMS Mean equal to 2.49, 1.65 and 2.88, respectively for sidestick, gamepad and touchscreen).

4 Conclusions and future work

The purpose of the trial was to compare pilot’s behaviour using three different inceptors - conventional sidestick, Xbox gamepad and novel touchscreen controller. The two formed hypotheses were checked against the results and confirmed to be true in most cases. While there is still a lot of work in touchscreen technology in flight decks and there is a long way before replacing the physical inceptors with digital ones, this research shows that even though the touchscreen controller scored the lowest on a SUS, majority of pilots were able to put the aircraft on the ground even in a challenging environment. Future tests will include comparison of pilots with non-pilots to see the effect of learnability, as non-pilots will not

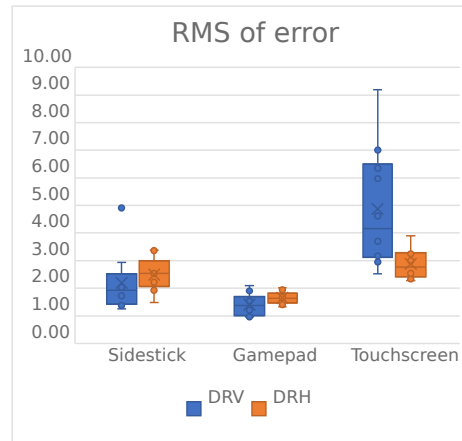


Fig. 9. Root Mean Square of error (deviation from the task objective).

have any experience in using the sidestick, hence won't be biased by the habits learned in flying schools. Further research will be conducted to find participants with no experience in neither of the controllers

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