Direct tactile manipulation of the flight plan in a modern aircraft cockpit

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ABSTRACT
An original experimental approach has been chosen, with an incremental progression from a traditional physical cockpit, to a tactile flight simulator reproducing traditional controls, to a prototype navigation display with direct tactile functionality, first located in the traditional low position, then located in front of pilots in desktop-like setup. The main findings are that naive tactile implementations bring a performance penalty compared to similar physical interfaces, but tactile approaches have a number of assets that will counterbalance this fact.

Author Keywords
Cockpit, tactile, interaction, usability

INTRODUCTION
The introduction of cathode ray tube (CRT) displays and computers in flight decks over the early 1980s allowed the development of Multi-Function Displays where the information could change upon crew selection [5], thus reducing the number of cockpit instruments and easing the pilot monitoring tasks. Cockpits have then gradually evolved towards larger displays and better fusion of data to provide the crew with mission-oriented information. As the next evolutionary step, the work presented is a part of the EU project ODICIS [4] on "One Display for a Cockpit Interactive Solution" aiming at designing a large single display cockpit with multi-touch tactile capability [3] that is no longer constrained by the physical boundaries between adjacent displays (Figure 1). This offers new possibilities to design a Human Machine Interface (HMI).

HCI Aero 2012, September 12–14, 2012, Brussels, Belgium

Figure 1: The ODICIS large tactile single-screen cockpit

However, this also raises a significant number of questions regarding potential pitfalls and, in their mitigation, how to still make the most out of this new tool. This is partially addressed in this paper with a quantitative and qualitative assessment of the potential value of direct tactile manipulation (i.e. manipulation of the visuals without necessarily using menus or buttons), taking the case of the flight-plan on the navigation display (ND).

RELATED WORK
In [1], Hoogeboom and Huisman tested three different scenarios using four pairs of experienced pilots. In these typical flight simulations, crewmembers were asked to use track-balls, touch-pads and touch-screens placed either on the front display or on the pedestal to interact with a flight simulator. In another experiment [2], pilots were asked to perform manual operations such as the change of autopilot

settings while handling warning messages and communicating with the other pilot. The present study is in the continuity of this literature, as the proposed tactile single-display cockpit HMI incorporates enhanced features that need to be tested on the same usability criteria [5].

EXPERIMENTAL SETUP

We report the qualitative and quantitative assessments of an early software prototype of navigation display (ND) that includes a possibility to modify the flight plan with direct tactile manipulation. This operation is traditionally done through the Flight Management System (FMS), which is nowadays integrated in the Multifunction Control Display Unit (MCDU). While the goal is to run the experimental navigation display on the ODICIS display (Figure 1), the part-task evaluations of this paper were, for practical reasons, performed on an off-the-shelf tactile LCD screen.

In order to compare the proposed user interface with existing systems, an identical scenario was performed on four different setups: (1) a baseline flight simulators with a physical MCDU; (2) a flight simulator with a touchscreen-based mock-up of a similar MCDU; (3) the prototype tactile ND located between pilots; (4) the prototype tactile ND vertically in front of the pilot. The two flight simulators are owned by Alenia Aermacchi in Torino, Italy, and all experiments were conducted there.

The participants consisted of three experienced professional civil air transport pilots flying Part 25 certified aircraft (Airbus A320, Boeing 777), age 42 to 51, and 11800 to 13000 flight hours. One pilot was equipped with an eye-tracker to validate the experimental setup, i.e. that pilots were behaving as anticipated. To avoid bias from learning effect, the trials were performed in a nearly randomized order {(3,4,1,2), (3,1,2,4), (1,2,4,3)}, as much as the organisational constraints allowed.

Scenario

The designed scenario assumes that a flight plan is already loaded onto the FMS. Pilots were required to add two waypoints α and β to the flight plan, remove waypoint α, and perform a "direct-to" γ (i.e. instruct the aircraft to fly directly to the waypoint γ, which was the next waypoint in the original flight plan prior to the addition of waypoints α and β). The full execution of this scenario was therefore neutral in that it did not ultimately alter the flight plan. In this way, it was possible to have the pilots repeat the actions, allowing the experiment to run many iterations, or "loops", of this scenario. Pilots were allowed 5 minutes to perform as many loops as possible.

Furthermore, an important consideration in the operational environment is that pilots are often required to multi-task. This situation was simulated by requiring the pilots to conduct another concurrent task, consisting of clicking on a graphical timer displayed on a separate touch-screen at least every 8 seconds (a value established empirically after a few dry runs). This would simulate the potential failure of a pilot to address an important second task (e.g. alert) in a timely manner. The hardware used for the timer was a telephone with a 10.8cm (4.3″) touch-screen (Samsung Galaxy S2), and attached in the cockpit in front of the pilots, i.e. on the yoke or similar, as visible e.g. on Figure 6.

Prior to the experiments, pilots had instructions and some free time to get familiar with both the setup and the scenario. The same scenario was used in all the four setups.

Baseline Simulator

Figure 2: Experiments in baseline physical simulator, with head-mounted eye-tracking equipment

The baseline simulator was a traditional cockpit setup, that of an Alenia C-27J Spartan aircraft, which is a medium-sized two engine military transport. The reason for using this platform was to have a representative baseline reference, close to systems currently in operation.

Tactile Traditional Simulator

Figure 3: Experiments in the traditional research simulator

The second platform used in the experiments was a research flight simulator with a touchscreen-based FMS (Figure 3) mimicking a physical MCDU. The configuration running during the tests was based on a twin-engine turboprop regional aircraft. The main instrument panel, central and overhead consist of a virtual reproduction onto five 22" Active Matrix TFT LCD displays (Elo TouchSystems 2240L) featuring single touch, surface acoustic wave-based touch-screen. The reason for choosing this platform was to assess the effect of the tactile interaction itself when compared to the physical interaction, while keeping as much of the rest as possible identical to the baseline simulator (e.g. ergonomics, menus, procedures…).

Prototype with Direct Tactile Manipulation

The third and fourth experimental platforms were based on a prototype of navigation display (Figure 4).

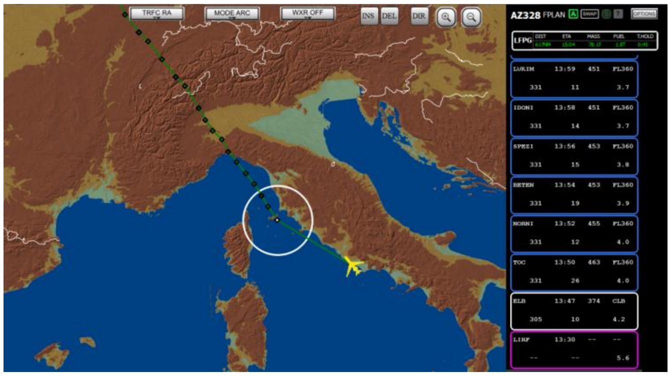

Figure 4: Screenshot of the prototype ND software

The navigation display provides the crew with navigation information, such as current position and flight plan, with the possibility of changing the information presented using tactile manipulation. The possible changes to the route consist of inserting a new waypoint, skipping a waypoint and directly flying to a waypoint (“direct to” function). To insert a new waypoint, the preceding waypoint is selected and then a double-click is performed on the map in the vicinity of the location of where the waypoint is to be inserted. A list of nearby waypoints is then displayed for the pilot to select. For the “direct to” functionality, a dedicated button is pressed and the relevant waypoint is then selected. The LCD screen for the part-task experiments is a 3M Multi-touch Display M2256PW, 56cm (22″), P-MVA technology, able to track up to 20 fingers with capacitive sensing, and a resolution of 1680×1050 pixels.

Figure 5: Experiments using the tactile prototype in the low position, and eye-tracking equipment

As shown in Figure 5, a first setup had the LCD screen mounted horizontally in a low position between the pilots. The reason for this setup was to minimise the differences with the tactile traditional simulator. Then, as visible in Figure 6, the LCD screen was mounted in front of pilots in a desktop-like configuration.

There was a natural progression with incremental changes from the baseline simulator, to the tactile traditional simulator, to the prototype in the low position, and finally the prototype in the desktop position.

Figure 6: Trial using the tactile prototype in the desktop position. Green timer (smartphone) on the right-hand side

Data Collection

In order to assess usability [5], the main performance indicator was the number of times pilots were able to complete a full loop of the scenario on a given platform. The second performance indicator was the number of timer control errors when pilots failed to click on the timer within the time laps (8 seconds). Data collection was achieved through the use of video recordings. A questionnaire was also given to the pilots to collect subjective ratings of experiment-related aspects and observations.

There was a software issue with the prototype that made it necessary for an operator to quickly reset the system after each loop of the scenario, resulting in the loss of a few seconds for the test subject. The data was corrected by applying a normalisation using a precise estimation of the time lost based on a video analysis.

QUANTITATIVE RESULTS

Figure 7 summarizes these results. The physical baseline and the prototype in the desktop position were about equally fast and the fastest of all setups to operate for the given scenario. The prototype in the low position ranks third, with the tactile traditional setup the slowest. It can also be observed that the min/max error-bars of the tactile-traditional setup do not overlap with those of the other setups, thus reinforcing the claim.

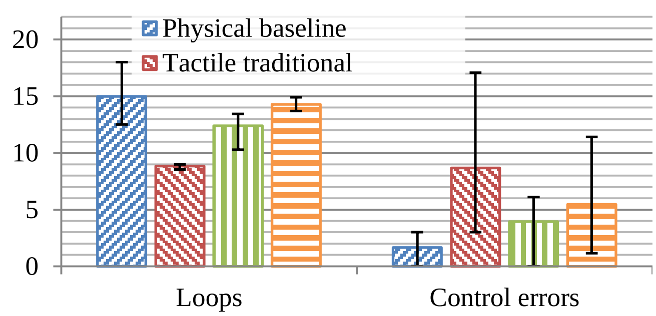

Figure 7: Graph of the quantitative results for the four different setups showing the number of loops performed (speed of execution), and the number of control errors (failures to click on the timer within 8 seconds). Error-bars with minimum and maximum values are included. (N=3)

Regarding the timer control errors, the trends are not just as evident, but the physical baseline also seems to have performed best (i.e. resulting in a lower number of errors), while the tactile traditional setup was the worst.

Even though there were only three participants, which is considered too little to perform a detailed statistical analysis, it is possible to see some trends, especially when taking into account the error-bars showing an interval ranging from the minimum to maximum recorded values. Furthermore, each participant repeated the scenario between 9 to 18 times for each setup (12.6 "loops" on average), which strengthens the validity of the results.

RESULTS FROM QUESTIONNAIRES

The main result from the questionnaires is that pilots would greatly welcome a tactile navigation display (ND), especially when large and located in front of them. Pilots also rated the reported experiments as quite relevant. On questions related to possible inadvertent actions of tactile systems (FMS, ND), pilots reported a slight increase of risk compared to traditional physical systems when located near the pedestal. However, a tactile ND located in front of the pilots was deemed less susceptible of inadvertent actions than a physical MCDU located between the pilots.

COMMENTS FROM PILOTS

A number of written and verbal comments were recorded.

Regarding the concept of direct tactile manipulation of the flight plan on the navigation display, pilots felt that this would increase situation awareness, could potentially provide more information at the same place and faster.

On all setups involving tactile interaction, some haptic feedback would have been desired, or at least audio. Noticeably, the touch-screen of the "tactile traditional simulator" was said to lack precision.

Several suggestions and recommendations relevant to further development of the single display cockpit have also been recorded. For instance, it was considered desirable to be able to graphically drag and drop the flight-plan line on the ND with a single finger. Such functionality would be very useful e.g. in the tactical avoidance of weather. A click on an airport should also provide details. On each waypoint, estimated time of over flying (ETO) should be provided. A vertical profile of the navigation should be available on request, together with additional information such as names of points of interest. Finally, participants considered that there should be the possibility to share or send the selected information to the other pilot.

DISCUSSION

This study suggests that there is a risk that the introduction of tactile technologies may lead to a performance penalty compared to physical versions of similar equipment. Luckily, the technology also brings in a number of new possibilities, such as direct manipulation, support better layouts and more efficient utilisation of the main instrument panel space. These advantages can mitigate the performance penalty as evidenced by a comparison of the results obtained with the tactile traditional setup and the prototype in the low position. Furthermore, when taking advantage of additional features provided by tactile systems, such as supporting the possibility to locate instruments, controls and indicators in more appropriate positions for a given flight phase, tactile and physical approaches tend to perform equally well overall, as indicated by the results obtained from the physical baseline and the prototype in the desktop position.

The concepts addressed in this work are still at low readiness level, while physical commercial FMS are mature and the participants highly accustomed to them. Last, it would be interesting to compare such tactile concepts with track-balls like found in Dassault Falcon business jets.

CONCLUSION

The introduction of tactile technology on the flight deck brings significant opportunities to the aviation sector, where a number of them can be seen positively by various stakeholders of the industry, including pilots, operators, and aircraft producers. However, the use of tactile technologies as a direct replacement of physical systems introduces a number of performance and ergonomics penalties and challenges. Therefore, tactile systems can only match and potentially perform better than their physical counterparts when concepts will be robustly designed and developed to sufficient maturity. This can only be achieved through rigorous testing and evaluation, in which the present work provides a contribution.

ACKNOWLEDGMENTS

This work is part of the EU project ODICIS [4] (2009-2012), led by Thales Avionics (France) and partly funded by the European Commission's Framework Programme 7 under grant number ACP8-GA-2009-233605. We would also like to acknowledge the valuable contribution of pilots Vanni Marotta and Marco Parenti Nardi from Alitalia.

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