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Human Interface Research of Civil Aircraft Cockpit Based on Touch Control Technology

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Abstract. Touch screen technology is an important direction of the aircraft cockpit technology development. More and more touch screen test units are applied in the cockpit. However, most of the touch screen interface design is only a simple copy of the physical interface, which does not bring any benefits to the aircraft, but will cause some safety effects. Fundamentally speaking, these test units did not consider the impacts of flight crew operating procedures, human factors, flight scenes, and other factors on touch screen technology. This paper gives some advantages and disadvantages analysis for the touch control technology and provides a new concept of cockpit overhead control panel based on the touch control technology. The overhead touch control panel can not only effectively reduce the workload of the pilot, reduce the weight of the system, but also ensure the same flight safety with the physical panel.
Keywords. Touch Control, Human Factor, Workload, Hybrid Layout, Ergonomics Evaluation.

1. Introduction

With the development of civil transportation and science technology, it's an inexorable trend for civil aircraft cockpit stepping into tantalization, intelligentization and visualization. Touch technology gets a lot of attention in civil aircraft area due to its technical characteristics of high integration, simple control, and intuitive display. Cockpit products using touch technology have been researched and come into service in military aircraft and general aviation area. These products can provide the same function as traditional ones. However, considering human factor and high level regulations from flight crew operation, there are still many restrictions for touch technology products being applied in the civil aircraft cockpit. This paper analyzes the application characteristics of civil aircraft touch technology, provides application assumption of products using touch technology and proposes methods for cockpit ergonomics evaluation based on the current situation of touch technology. [1]

2. Human-machine Interface Development in Civil Aircraft Cockpit

The human-machine interface design in civil aircraft cockpit is a concentrated embodiment of the close combination of human and aircraft. The interface design can affect the operation and observation of pilots. Signals and messages from the cockpit during flight have an impact on judgments, decision, measurements, and safety. The cockpit is developing with the advance of technologies.

The analog instruments are widely used in the early civil aircraft cockpit to realize definite functions. It requires a strong capability for the flight crew to monitor the real-time state of these

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instruments. Figure 1 shows the dense physical instruments used in the cockpit of B747-200 which went into service in 1971.



Figure 1. Cockpit of B747-200. [2]

The B787 is a Dreamliner delivered by Boeing in 2011 and PFD/MFD was applied to replace most of the physical instruments. This cockpit was called “glass flight deck”[3] by Boeing and gradually accepted by pilots, which is shown in figure 2. It is simpler and safer for pilots to operate an aircraft because signals are integrated to display in “glass flight deck”.



Figure 2. Cockpit of B787. [3]

B777X is about to be developed by Boeing in the future. Touch MFD will be used on B777X as shown in Figure 3. Meanwhile, Airbus A350 is setting out to research touch technology and try to use it on lower display and pedestal zone.



Figure 3. Cockpit of B777X (in researching).[4]

Touch screen technology is broadly used on G650 as shown in Figure 4. Thirteen touch screens integrated functions of multiple systems like flight regulation, communication and weather radar and so on to replace most of the switches. It is not a simple replacement of operation devices. The cockpit

is highly integrated and intelligentized and pilots can be completely immersed in the cockpit by the application of touch screens.



Figure 4. Cockpit of G650. [5]

In summary, civil aircraft experienced significant changes from instrument cockpit to glass cockpit by looking at the development history of b747-200, B787, B777X, and G650. Today, the glass cockpit is developing into touch cockpit. The cockpit is becoming more intelligent, lower workloads, and less amounts of the flight crew.

3. The feature of Touch Screen Technology

It is an obvious conclusion from the development of cockpit human-machine interface that touch cockpit is an inevitable trend of in the future. Touch screen technology is more intelligent and highly integrated which can effectively reduce the weight of the system and the workload of pilots. Furthermore, there are still have some difficulties in human factors of the touch screen technology, which impacts the pilot's human-machine interaction operation.

3.1. Digitization

The development of digital technology is the precondition for the application of the touch screen in the aircraft cockpit. Whether the control interface adopts the touch technology is greatly affected by the aircraft terminal system. On the one hand, due to the high requirements of aircraft safety, commercial aircraft terminal system with high safety level tends to adopt the traditional physical connection and interface of these systems to realize by touch technology. On the other hand, some system functions must be completed without power on the aircraft which are also hard to apply touch technology. Therefore, the combination of touch control and physical control will be a major direction in cockpit human-machine interface design for civil aircraft currently.

3.2. Integration of Display and Control

The integration of display and control is a major advantage of the development of touch screen technology. The integration of display and control means that a touch screen can display the information required by the user and direct operation can also be implemented in the corresponding area. The visual feedback (information change) generated by the operation can also be presented in the same area. The display area is completely separated from the control area in traditional cockpit thus more pilots efforts are required to switch between two different areas to obtain the status information of the aircraft. Therefore, the development of touch technology makes flight control more intuitive and efficient.

3.3. Intelligent

Automated disposal procedure is an advantage by adopting the touch interface. The fundamental purpose of touch cockpit is to reduce the workload of pilots. The touch interface cannot make decisions and deal with tasks for pilots. However, with the development of intelligent technology, the machine behind control interface will automatically solve more tasks for pilots.

The fundamental purpose of touch cockpit is to reduce the workload of pilots. The touch interface cannot make decisions and deal with tasks for pilots. However, with the development of intelligent technology, the machine behind control interface will automatically solve more tasks for pilots. The pilot is a scarce resource in civil aviation and the number of the flight crew is a key factor affecting the profitability of an airline. The number of pilots on an aircraft has been reduced from five to two with the development of aircraft. With the development of touch screen intelligent technology, the single pilot is becoming possible.

3.4. Redefine of the working area

The "cross area" in the civil aircraft cockpit is the main area for cockpit display and control. Control functions are mainly located at the overhead and central console area and display functions are concentrated at the instrument area. Glareshield area integrates display and control functions with FMCP as its pivotal equipment. Glareshield is the core area for pilots to perform forward-looking operations and gain external information faster while operating the equipment located in this area. More and more aircraft are now equipped with head-up displays (HUD), which proves that the concept of forward-looking operation will be the focus of cockpit development in the future.

The development of touch screen technology has greatly reduced the traditional control and display interface and makes more display and control functions to be concentrated in the forward view area possible. The cockpit layout will be changed dramatically.

3.5. Human Factors

The application of touch screen technology has enormous advantages in the civil aircraft cockpit. However, some defects and problems need to be paid attention to, especially human factors, which will be the key factor in the development of touch screen technology.[6]

3.5.1 Misoperation. Civil aircraft cockpit is a narrow space and the aircraft can enter into turbulence during the flight. As a cockpit control interface, the touch screen is easier to be triggered by mistake compared with traditional physical control devices, which is an issue that needs to be evaluated. Based on the misoperation of the touch screen, there are mainly the following considerations:

- Touch Screen Activation. The touch screen should be in a dormant state when it has not been used for a long time. The touch screen can display normally but the operation function is in a dormant state. When the operation is required, the touch screen control function should be activated in some way.
- The Logic of Operation Response. Touch screen button should be activated when the finger leaves the screen. That means a certain area can be activated only when the operator's finger leaves. When a pilot accidentally touches the screen or clicks on the wrong area, he can move his finger to another area on the screen and then lift it up thus the corresponding control function of the wrong area will not be activated.
- Operation confirmation. Touch controls should be designed to provide a confirmation step before activating a function to prevent misoperation. It is also necessary to balance the confirmation steps with the increased pilot workload. The operation confirmation function should be set for the functions with high safety level on the aircraft which will cause irreversible safety impact on the aircraft thus needed to be confirmed twice before triggering.

3.5.2 Operation Feedback. A certain amount of operating force is usually required to confirm the operating instructions on physical devices. For example, the key operation is accompanied by feedback such as sound and force, and the joystick will transmit a reaction force feedback to the pilot when it is operated. However, the touch screen is a static plane which is difficult to induce the pilot's manipulation perception. Although operation feedback can be generated by means of sound and vibration, it is still unable to establish a perfect information feedback mechanism. The design of appropriate information feedback mechanism of touch screen technology used in the complex civil aircraft cockpit is one of the main contents of its research.

3.5.3 Accuracy of Display. The design of the display interface should inform the pilot which parts are touchable and which are not in a very direct and clear manner. If a certain position on the interface is thought to be touched to achieve a certain function but corresponding feedback is not received after clicked, it will frustrate the pilot's operation and affect the pilot's mood and normal operation.
The effective touch function area on the display screen should be clearly defined to ensure that the pilot can easily identify the effective control function area. Finger movement within a predetermined valid area shall not inadvertently operate other valid areas.

3.5.4 Operational Stability. The touch screen operation usually requires a pilot’s arm to be suspended which can easily cause fatigue [7]. Traditional physical devices can provide operating fulcrums for the pilot, which is helpful for the pilot to select the target accurately during the flight. Without providing fulcrums, touch screen operation has higher requirements for pilots to accurately select the target which results in increased pilot fatigue.

3.5.5 Operational Efficiency. Touch screens used in civilian aircraft can reduce weight and save space. However, operation pages are overlaid which makes pilots spend more steps to complete triggering. It is particularly important for the operation which affects the flight safety and processing urgently needs the pilot to carry on. For this kind of operation, pages can be set by touch screen logic to quickly jump out, so that the pilot can efficiently handle the relevant operation. From the analysis of the operation mode of the display control device, the touch screen device is more suitable for the operation that can be completed by clicking, such as continuous input, click, etc., which is better than the traditional input inefficiency. But in precision adjustment or continuous adjustment aspect, the superiority of the touch screen is not obvious, even inferior to the traditional physical input equipment. Therefore, the touch screen should be applied for input operation, such as MCDU on the central console and buttons in each area to replace traditional control equipment. Devices like handles, knobs, and joysticks should be better not using the touch screen.

3.5.6 Cockpit Commonality. There is often a process involved in the acceptance of new technology for both airlines and pilots. More training is needed for pilots who are familiar with traditional aircraft models to learn new technologies which mean airlines need to spend more operating costs. Therefore, more common issues of cockpit touch screen should also be considered to reduce extra costs in the process of operation.

3.5.7 Sunlight readability. The display information on the touch screen should be readable under all predictable lighting conditions. Lighting conditions to be evaluated should include at least direct sunlight to the display screen, dusk, night flight through clouds, thunderstorms and other flight scenes. The glare in a variety of expected flight scenes should be paying attention to due to the widespread use of touch screens in the cockpit. Design criteria or specification of the display information itself, such as the design specification of character size, key size, and key color should also be considered while

evaluating the flight scene. It is necessary to conduct tests and analysis and research on touch screen devices to determine specific design requirements while researching in the touch screen.[8]

4. Application of Cockpit Touch Screen

The purpose of the cockpit touch screen technology application is reducing the workload of flight crew under safety conditions. At present, the touch screen technology application is still in the primary stage, because of the low level automation in the cockpit. There are some considerations of the application touch screen technology, the details as follows:

- The hybrid layout of the touch screen interface and the physical interface. According to the advantage of these two technologies, it is better to provide a hybrid layout interface in the cockpit. The physical interface is preferred to perform the high safety, fast operation, and continuous holding functions. The touch interface is preferred to perform the low safety and single point touch functions.
- Pay more attention to reduce the pilot workload before the flight. There is a better environment in the cockpit before the flight, and pilots have a lot of work to deal with. The touch screen technology can increase the working efficiency before the flight, and improve the dispatch rate of the aircraft.
- No paper concept. No paper concept makes more space in the cockpit and more efficient of data updating and query. The touch screen technology provides a better condition for the no paper concept.
- Smart guidance. In the flight, pilots may not have enough time to deal with the failure problems in the emergency condition. The application of touch screen technology can guide pilots to make the choices according to the AFM. The pilots can allow the computer to deal with some actions based on the choices, but the final decisions should be made by pilots based on the safety consideration.

Based on the above considerations, this chapter gives a proposal of the touch screen technology applications on the current technology.

4.1. Graphical Flight Plan

The traditional flight plan receives the text date from the keyboard. The pilot needs to remember the number of the airport, and more time to input it. The graphical flight plan can reduce the reaction time of in pilots' mind, reduce the workload of the flight crew, and improve flight safety. The graphical flight plan with touch screen has some other advantages.[9] Pilots can quickly change flight plans on the touch screen, get the fight plan from the ground automatic, zoom in or out the flight path on the touch screen in order to get the overview of the path. In summary, the graphical flight plan with the touch screen can improve the efficiency of pilots.

4.2. Electronic Flight Bag (EFB)

As an electronic information management and display system mainly used in the cockpit, EFB with touch screen technology can display a variety of aircraft information data instead of the traditional paper data, and carry out the basic aircraft performance calculations. The EFB installation can be fixed or portable.[10] The main contents displayed in the EFB include navigation charts, meteorological charts, flight manuals and logs, passenger lists, electronic maintenance manuals, electronic checklist, and other related information. The pilots can query manuals and data more quickly and effectively through the EFB with touch screen technology. While improving flight safety margin, an aircraft can save more than ten kilograms of flight data paper a year.

4.3. Traditional Overhead Control Panel

As we know, most of the control commands come from the overhead control panel in the cockpit. The traditional cockpit overhead control panel contains nearly 200 control devices. There are so many factors of control devices arrangement need to be considered.

- Golden Area of Overhead Control Panel. Generally speaking, the traditional cockpit overhead control panel is divided into three columns, the middle column area which can be easily operated by the pilot and co-pilot. According to the aircraft flight manual, the important control devices which need to be operated by the pilot and co-pilot are generally concentrated in the middle column. On the other hand, the middle area of the control panel is an ergonomics comfortable area for pilot operation. The power supply, fuel, and air condition system control devices with high operating frequency are generally concentrated in this area. The front area of the cockpit overhead control panel is the ergonomics uncomfortable area for pilot operation. It is difficult to carry on the "press" action in this area. Most of the toggle switches should be arranged in this area. Thus, the golden area of the overhead control panel is concentrated in the red rectangle area of Figure 5.

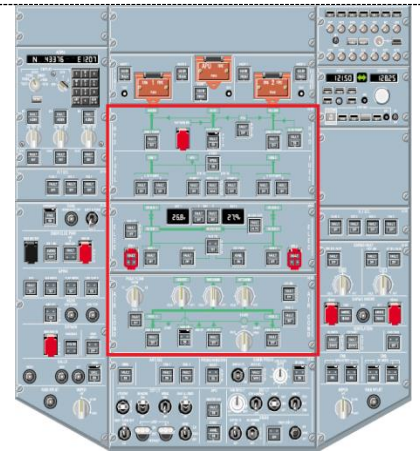

Figure 5. A320 Cockpit Overhead Control Panel. [11]

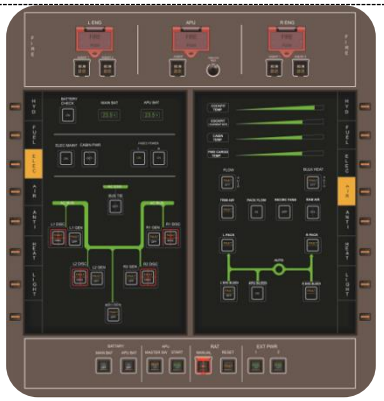

Figure 6. Cockpit Overhead Touch Control Panel.

- Operation Habit. The layout of traditional overhead control panel devices needs to consider the operation sequence according to the electronic checklist. So that the operation sequence should conform to a certain rule in the overhead control panel. In this way, the arrangement of overhead control panel devices should conform to the pilot operating habit, in order to reduce the workload of the pilot.
- Mistake Operation. The devices with similar shape and redundant design in system logic should be arranged separately in a distance to prevent mistake operation under the heavy workload in the cockpit.

In summary, there are still some limitations for the layout of the traditional overhead control devices, and it will make some difficult for the engineering design. Therefore, before the application of touch screen technology in the cockpit, it is necessary to make innovations in the layout of overhead control devices so as to take the advantages of touch screen technology. [12]

4.4. Overhead Touch Control Panel

This chapter gives a proposal of the hybrid overhead control panel, which combines physical and touched control functions, as shown in Figure 6. There are the following characteristics for the overhead control panel with touch screen.

4.4.1 Hybrid Layout. The overhead control panel adopts a hybrid layout of physical devices and touch screen, which takes advantage of the touch screen and also makes the consideration of the aircraft safety.

- The hybrid layout consists of two dual-redundant touch screens, which provide the control interface for the pilot and co-pilot respectively, which not only ensures the safety of the system but also meets the ergonomic operation of the pilot and co-pilot.
- The physical devices such as engine fire controls and power system controls should be consistent with the traditional controls. Because these control functions failure will make a big impact on aircraft safety. The pilots need high-reliability controls for these function. On the other hand, the pilots still need to switch the aircraft power on if the touch screen loses power, so it is better to use mechanical controls for the power system.
- In order to achieve better ergonomics, the important and low-frequency physical devices are located above the touch screen, and the important and high-frequency devices are located below the touch screen.
- The main menu inside the touch screen adopts the longitudinal menu, which is close to the pilot and co-pilot. In this way, the longitudinal menu not only conforms to the pilots' operating habits but also meets the ergonomic requirements.

4.4.2 Smart Warning System. The overhead touch control panel can push the corresponding warning information automatic. There are two ways for pilots to deal with warning procedures: in the emergency situations, the lower risk warnings are automatically processed by system CPU; For the higher risk warnings, pilots can operate step by step according to the pushed information, and display the results of the operations on the touch screen. The smart warning system greatly reduces the workload of the pilots in emergency situations. At the same time, there are two columns of push buttons with annunciators, which are located on the left and right sides of the touch screens. The pilots can quickly enter into the operation page of the touch screen with pressing the corresponding push button when the warning occurs.

4.4.3 Programmed Electronic Checklist. In the traditional aircraft operation procedures, pilots need to make a step-by-step operation inspection according to the paper operation procedures. The electronic checklist is loaded in the touch screen, and the pilots can carry on the checklist automatic or semi-automatic according to their needs. In the fully automatic mode, the checklist would be done with one key operation, the pilots only need to monitor the result after the operation. In the semi-automatic mode, the checklist would be done by the pilot’s step by step operation according to the recommends of the touch screen.

4.4.4 Integration of Display and Control. The touch screen combines displayed information and controls on the same page. The control results of the system can be seen, which greatly reduces the workload of pilots.

4.4.5 Operation with Holding. In the middle of the two touch screens, a grip groove is designed for pilots to grip when they operate with one hand. When the pilot’s hand is in the holding status, the control finger can cover the whole touch screen control panel because of the suitable dimension of the touch screen. In this way, the design feature can greatly reduce the fatigue of pilots and improves control stability.

5. Ergonomics Evaluation

For the installed system and equipment, it shall be designed to ensure that the intended functions can be performed under any foreseeable operating condition. [13] The touch screen panel shall be involved in the closed-loop of the functions for each system. It can be judged that the touch screen panels meet the aircraft functional requirements by the ground function test of each system.

On the other hand, as a new type of human interface, the touch screen panel shall be performed by ergonomics evaluation in the cockpit. There are two kinds of subject evaluation method were used for the human factor evaluation of the flight deck HMI. One is the static evaluation based on the flight deck interface and description in JDP phase. The other method is the dynamic evaluation based on the typical scenario tasks in the verification phase.[14] The dynamic evaluation is very important for the touch screen control panel, which needs a specific platform with part or full flight deck system functions to perform the evaluation.

This chapter suggests two kinds of dynamic evaluations. One is the evaluation based on the Simulation Cockpit. In the Simulation Cockpit evaluation process, it needs to define all kinds of scenarios in the flight. The engineers can evaluate the HMI to make sure all the functions of the touch screen panel to fulfill with the aircraft requirements in the different scenarios.[15] The other evaluation based on real aircraft. The pilot needs to give the evaluation of the touch screen panel in the normal flight. The evaluations do not need to cover the full functions. The pilot can give the conclusion that whether the touch screen panel is high efficiency in the flight.

6. Conclusion

At present, there are some big changes for the development of civil aircraft cockpit. In order to reduce the workload of the flight crew, increase the efficiency of the flight crew, improve the flight safety, and reduce the airline operating costs, many new ideas and technologies of the cockpit are created by the engineers. Such as the concept of the single flight crew, the application of touch screen control technology, and the active side stick. It can be found that the development of aircraft is always in the direction of higher intelligence through these new technologies. Therefore touch screen technology will be widely used in civil aircraft in the next 15 years, although there are still some ergonomics problems in the current applications.

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