Airworthiness Compliance Criteria in Ergonomic Design of Cursor Control Device for Civil Aircraft

Lei Wu(✉) and Jian Xu

Shang Aircraft Design Research Institute, Shanghai 201210, China
wuleil@comac.cc

Abstract. Cursor control device (CCD) has been applied to the integrated avionics system in the cockpit of modern civil aircraft, and gradually becomes one of the main controls in the cockpit. From the perspective of operation frequency and workload, ergonomic design of cursor control device, especially the design of installation location, will become an important aspect of ergonomic airworthiness. Based on anthropometric data and ergonomics combined with biomechanical theory, the control posture requirement of CCD is determined by analyzing the operational situation of CCD, and the reasonable installation location of CCD is calculated by computer aided design technology. From the results of computational analysis and evaluation, there is theoretically a limited installation area, which can meet the needs of most pilots to operate CCD conveniently and efficiently over all flight phases. While satisfying the airworthiness provisions, the relevant theoretical methods and quantitative analysis results can be used as criteria to show the compliance to the authorities.

Keywords: Civil aircraft · Avionics · Cursor control device · Ergonomics

1 Background

With the rapid development of electronics and computer technology, the integrated degree of avionics system is getting higher and higher, and its functions are becoming more and more complex. Especially in interactive control, if each function is assigned an independent control, they will not only challenge the already constraint cockpit space, but also make pilots more difficult to operate.

Through the combination of virtual control technology and cursor control device, a new generation of integrated avionics system has the technical basis of providing pilots with more efficient, safe and convenient means of interaction. However, due to the late entry of new technology into the cockpit, further research on the ergonomic design of CCD, especially in the installation location, shape and size, and its quantitative airworthiness compliance standard is still needed. Traditional cockpit workspace design methods tend to use human body model data as the basis, and computer aided design tools (such as JACK) are used to analyze ergonomically the vision of existing design solution and the accessibility of control devices [1]. The analysis results can be used as the basis of iterative design or evidence of airworthiness. However, due to the limited

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cockpit space and various devices, a slight move in one part may affect the situation as a whole. It will reduce the efficiency of this “passive” evaluation and design, and it is difficult to ensure the repeatability of its theoretical methods.

CCD is one kind of hand controller. In the 1990s, with the mouse becoming the main input device and its wide application in the field of personal computers, related literature [2–4] discussed the shape of the mouse and the influence of office space design on upper limb motion constraint and manipulation performance. With the development of sports medicine and biomechanics [5, 14], the ergonomic design of hand controller has a certain theoretical basis. When considering its application scenario, the selection of corresponding design theory will be the theoretical basis to show the certification of this kind of control device. This “active” design and evaluation method will also greatly improve the efficiency of design work.

2 Brief Introduction to the Application of CCD in Civil Aircraft

Cockpit Display System (CDS) has become a human machine interaction platform for modern civil aircraft airborne system. It accesses virtual Graphical User Interface (GUI) components by cursor, realizes the interaction between pilots and many application functions such as navigation map, flight management, integrated surveillance, data link, radio tuning, electronic checklist, and so on, thus realizes platform and modular system architecture, reduces or even abandons independent computing processing and control Unit.

CCD belongs to one of the multifunctional controllers. It generally controls the motion trajectory of the cursor by means of a trackball, joystick, touchpad, etc., in order to focus and control the state of the GUI components and realize the interaction between the pilot and the aircraft system.

Typical interaction between a cursor and GUI components via a CCD is shown in Fig. 1.

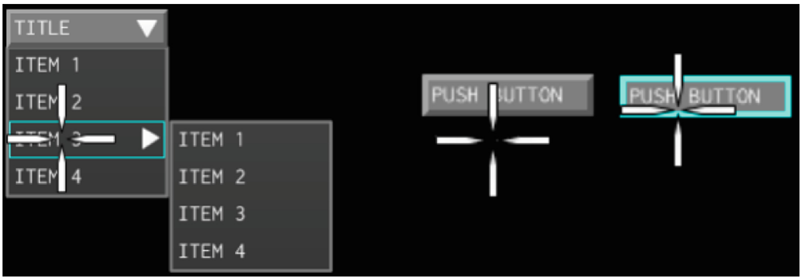

Fig. 1. The interaction between cursor and GUI component

The installation of CCD and ergonomic evaluation scenarios on some aircrafts are shown in Fig. 2.

Fig. 2. Examples of CCD installation and evaluation

From the perspective of human machine interaction, the advantages of integrating many functional applications on CDS platform are as follows:

a. The interaction interface concentrates in the pilot's main field of view, which decreases the head movement required for interaction, and the forward-looking attitude helps to maintain the pilot's external situation awareness;
b. Based on GUI interaction specification, the interaction behavior of human machine interface of each system is easy to be unified, which not only reduces the training difficulty and cost, but also lessens the probability of human errors and the number of dedicated control devices.
c. The system can provide flexible and intuitive interactive experience and simplify flight crew's operational action.
d. Facilitate the upgrade and expansion of system functions.

Due to the fact that many system functions rely on CCD for interaction, it is used very frequently in the cockpit [2, 12]. In addition, the CCD usage scenario covers almost all flight phases, including the phase of high work load in the terminal area [7, 15, 17–19] (for example, with frequent switching of communication frequencies, selection of standby flight plans, alteration of approach routes, etc.). Therefore, CCD has been clearly listed as an important cockpit control device in the relevant advisory circular [13], and its importance is equivalent to that of operating equipment such as aviation and throttle control.

Because CCD belongs to hand control equipment, in addition to satisfying the basic requirements of general controller such as two-dimensional layout, lighting, label and accessibility, special requirements such as hand stability, compatible operation in vibration environment and reducing operation fatigue need to be considered.

From the above, the airworthiness compliance criteria of CCD ergonomics design will be significantly different from that of common control devices.

3 Analysis of Relevant Airworthiness Clauses

The provisions related to CCD in 25 regulations of CAAC, FAA and EASA are summarized as shown in Table 1 [8–10]:

In terms of the frequency and workload of operation task, especially installation position, the ergonomic design of the cursor control device will be an important aspect of its airworthiness certification.

Table 1. Airworthiness regulation apply to CCD

Relevant airworthiness clauses	Regulation chapter	Scope of application
Each cockpit control must be located to provide convenient operation The controls must be located and arranged, with respect to the pilots' seats, so that there is full and unrestricted movement of each control without interference from the cockpit structure or the clothing of the minimum flight crew (established under CS 25.1523) when any member of this flight crew from 1.58 m (5ft 2 in.) to 1.91 m (6ft 3 in.) in height, is seated with the seat belt and shoulder harness (if provided) fastened	25.777(a) 25.777(c)	Cockpit controls
Each pilot compartment and its equipment must allow the minimum flight crew (established under CS 25.1523) to perform their duties without unreasonable concentration or fatigue Vibration and noise characteristics of cockpit equipment may not interfere with safe operation of the airplane	25.771(a) 25.771(e)	Pilot compartment
Each item of installed equipment must – (1) Be of a kind and design appropriate to its intended function; (2) Function properly when installed	25.1301(a)(1) 25.1301(a)(4)	Function and installation
Flight deck controls and information intended for flight crew use mustbe accessible and usable by the flight crew in a manner consistent with the urgency, frequency, and duration of their tasks	25.1302b(2)	Human factor
The minimum flight crew must be establishedso that it is sufficient for safe operation, considering – The accessibility and ease of operation of necessary controls by the appropriate crew member	25.1523 (b)	Minimum flight crew

Considering the functional characteristics of CCD, the related ergonomic provisions can be summarized as follows:

a. Because of the interaction of many functions and its operation frequency [11], the position of CCD should ensure that the pilots in a certain range of height (and arm length) can operate easily, and the operation posture of hands and arms should be conducive to preventing fatigue;
b. The shape and position of CCD should be helpful for pilots to resist the adverse operation effects caused by vibration environment.

For flight deck system controls, the Federal Aviation Administration of the United States issued a special advisory circular (AC) in 2011, namely AC20-175. Considering the convenience of the use of CCD, this AC suggested that the CCD should be placed in or near the pilot's natural hand position, and should be combined with the use of hand stabilization device or arm support device. The aim is to minimize the movement of the hand and arm and to facilitate the operation of pilots, especially when pilots have time pressure.

Compared with the airworthiness clause, AC20-175 further explains the position of the hand and arm when operating the CCD, but the clause also requires that pilots within a certain height (and arm length) range be easy to operate, which is based on anthropometric statistics of Americans in the 1980s, corresponding to 5% of females and 95% of males, respectively. The core of the issue is that the arm length of the crowd in this area is obviously different, and the CCD can only be installed in a fixed position in the cockpit. Then, under normal sitting posture, whether it is possible for the natural hand positions of the above pilot crowd to be concentrated in a limited position range will be the key to prove the airworthiness of CCD ergonomic design.

4 Compliance Strategy of CCD Ergonomic Design

4.1 General Design Principles of Hand Controller

Because of its wide application scenarios and high frequency of use, hand controller has always been one of the hot and difficult points in ergonomics.

In addition to functional design, the design of hand controller also requires comprehensive knowledge of anatomy, anthropometry, and kinesiology. The cumulative effect trauma (such as carpal tunnel syndrome, tenosynovitis, trigger finger, tennis elbow, etc.) caused by improper design has a high incidence in daily life and work.

The basic principles for ergonomic design of hand controller include [14]:

a. Maintain wrist level during operation to avoid compression of adjacent tissues, as shown in Fig. 3;
b. Avoiding repeated finger movements;
c. Inclusive design. That is to say, anthropometric statistics for different races, from 5% female to 95% male and left-handed people are considered.
d. When the carpal canal is in the middle, the grip force is the greatest.

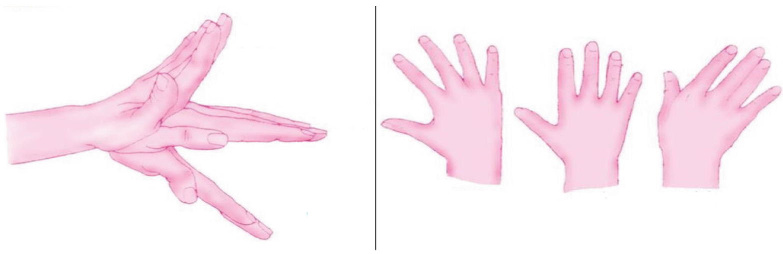

Fig. 3. Gesture of hand

4.2 Consideration of CCD Ergonomic Design

The ergonomic design of CCD is mainly divided into the following aspects:

a. Shape and size of the grip;
b. Mounting position of the grip;
c. Size and position of the trackball or touchpad;
d. Gain and data delay of the trackball or touchpad;
e. Size and position of the cursor selection key.

Obviously, the mounting position of the grip is the decisive factor to support the hand and drive the arm posture through the wrist joint. The shape and size of the grip will determine the hand pattern and the position and size of the trackball and cursor selection key. In addition, the combination of the both is a decisive factor in determining wrist posture. Therefore, the design methods for these two aspects will directly determine the applicable criteria and compliance of airworthiness clauses.

5 CCD Ergonomic Design Method

5.1 Scenario Analysis of CCD Use

The human-machine interaction system which combines display and control generally adopts the principle of “display above, operate below”. That is to say, the display interface is generally located above the control device to avoid obscuring display information during operation. Relevant design principles are common in industrial standards. Therefore, the CCD is usually installed on the central pedestal of the cockpit.

As far as the interactive process of virtual control is concerned, the operation tasks of cursor movement and keyboard input are serialized. Therefore, CCD and multi-function keyboard (MKB) should be arranged adjacent to each other. In view of the need of grip support and stabilization of hand, MKB should be placed in front of CCD.

In order to improve the safety of human-machine interaction system operation and aircraft dispatch rate, the operation functions of CCD and MKB should be backed up mutually.

As stated above, the operation of the CCD covers almost all flight phase, so:

a. In the terminal area, pilots should be able to use CCD efficiently when seated at design eye position(DEP) of the cockpit and fastening seat belts and shoulder straps;
b. During the cruise phase, should be able to easily use CCD when flight crew moving the seats backwards and deviates from the cockpit design eye position, and fastening the seat belt, with the lower operating frequency.

5.2 Selection of Appropriate Anthropometric Data

The anthropometric data is the basis of analyzing and designing the position and shape of CCD grip. Ethnic factors should also be taken into account in the selection of anthropometric data. The design data in this paper come from ISO-TR-7250-2 [20] of International Organization for Standardization.

The anthropometric data of typical ethnic groups in the United States, Germany, the Netherlands, Italy, Japan, Korea, Thailand, Kenya and other countries are collected in this standard. It should be noted that there is a big gap between the corresponding percentage data of some ethnic groups and the airworthiness provisions, which should not be considered.

The anthropometric data of Germany, Japan, Korea and Kenya are used in this paper.

5.3 Determine the Operational Posture

According to the above analysis, when the fight crew is seated at the cockpit design eye position, and fastening the seat belt and shoulder strap, if the upper arm is naturally drooping and the palm is put on the grip, it can maintain the wrist at right position. This posture can avoid the muscular tension from the shoulder and arm and minimize the pressure of the shoulder joint and elbow joint. It is more beneficial for pilots to operate CCD comfortably and efficiently for a long time. At this time, with the wrist at the right position and palms in the median position, it is convenient to grasp the CCD grip in adverse environment.

In addition, it should also avoid the occurrence of outer surface of CCD against palms. Improper long time compression will lead to pain and numbness in the arms and hands. Therefore, the muscle group with 1/3 palms from the wrist is chosen as the reference point to support the palm, thus avoiding the nerve intersection of the hand. To sum up, the reasonable attitude of pilots to operate CCD is shown in Fig. 4.

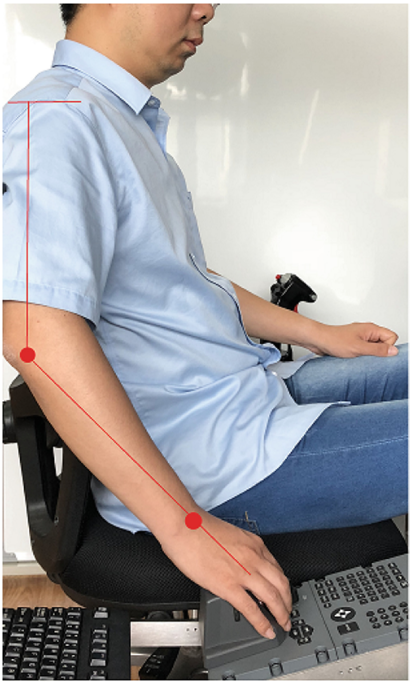

Fig. 4. Proper attitude of handling CCD

5.4 Computer Aided Design and Analysis

The required human anthropometry data include:

a. Height of eye (sitting position);
b. Height of shoulder (sitting position);
c. Distance between shoulder and elbow;
d. Distance between elbow and wrist;
e. Palm length;
f. Width between two acromia.

Based on the above data, the geometric parameters of a person operating CCD in a reasonable manner under the sitting position are sorted out. According to the movement ability of the human arm, if the upper arm is kept naturally drooping, in theory the forearm will be in front of the human body with elbow joint as the center, drawing about 1/4 of the spherical surface, in this problem only take the second half of the spherical surface, that is, 1/8 of the spherical surface as a research reference. When the eye coordinates corresponding to the sphere are aligned with the design eye position of the cockpit, the envelope of operating CCD can be obtained by each race in a reasonable attitude, as shown in Fig. 5.

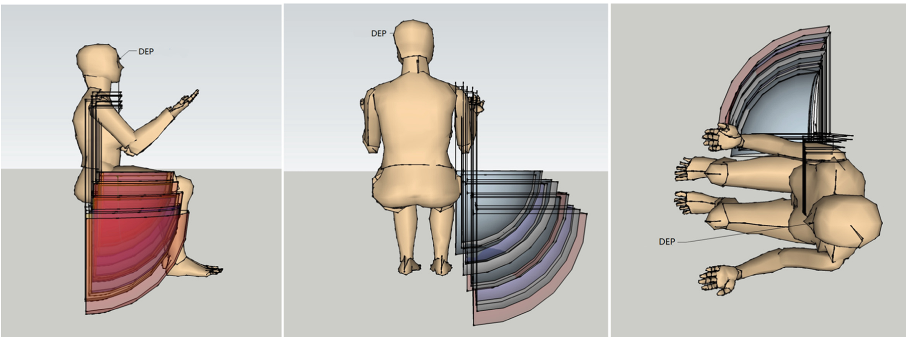

Fig. 5. Proper envelope of operating CCD

On the side of the central pedestal which is close to the human body, the intersection of the vertical plane along the heading and the envelope surface will be obtained as shown in Fig. 6.

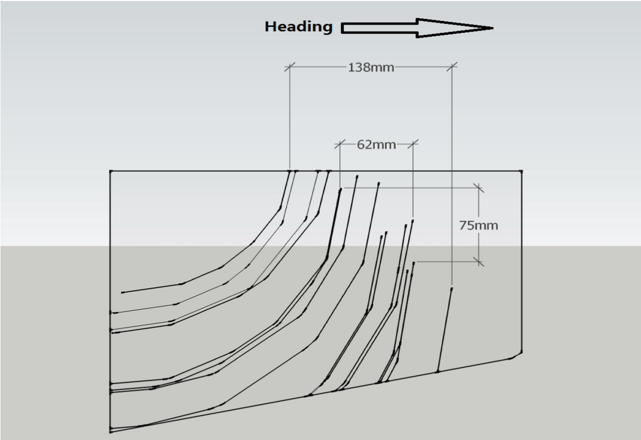

Fig. 6. Intersection line of envelope on the vertical plane

The arcs on the vertical plane in Fig. 6 show the distribution of all palm reference points of several ethnic groups when they operate CCD reasonably. On the far left is 5% Korean women and on the far right is 95% Kenyan men. Considering that 50% of the population, that is, the majority of the population should be comfortable to operate, it is not difficult to find that when focusing on the analysis of the crossings of 50% of the population, these crossings are relatively concentrated, and can even contain almost 95% of German men.

After measuring and analyzing the computer model, the support reference points of the palm in the operation of CCD are approximately distributed in an area of about 62 mm in length and 75 mm in height along the heading. The size of this area is much smaller than the difference in height (arm length) in anthropometric data.

If it is considered that in cruise phase, the pilots can easily use CCD when moving their seats backwards, it is suggested to select the reference points which are a little back in that area so as to be compatible with the pilots' operation at that time.

6 Conclusions

In this paper, the airworthiness clauses and advisory circulars applicable to CCD are analyzed. According to the daily use scenarios of CCD, based on the design principle of hand controller, the human anthropometry data in ISO standard is extracted extensively. The posture with reasonable operation on CCD is modeled by computer aided design technology, and the following conclusions are drawn:

a. In the case of sitting position, the size of the body has a limited impact on the location of CCD installation;
b. In theory, there is a limited position range, which can satisfy the pilot to operate CCD conveniently and efficiently in all flight phases, so as to comply with the requirements of airworthiness clauses;

c. The calculation method and results in this paper can be used as one of the methods and criteria for airworthiness compliance of CCD ergonomic design.

References

1. Su, R.E., Xue, H.J., Song, B.F.: Ergonomic virtual assessment for cockpit layout of civil aircraft. Syst. Eng. - Theory Pract. **29**(1), 186–191 (2009). (in Chinese)
2. Thomas, J.A., et al.: A conceptual model for work-related neck and upper-limb musculoskeletal disorders. Scand. J. Work Environ. Health **19**(2), 73–84 (1993)
3. Armstrong, T.J., Martin, B.J., Arbo, A., Rempel, D.M., Johnson, P.W.: Mouse input devices and work-related upper limb disorders. WWDU **3**(C), 20–21 (1994)
4. Richard, P., Robin, C.: Design criteria of an ergonomic mouse computer input device. SAGE J. **39**(5), 369–373 (1995)
5. Guo, X., Fan, Y.B., Li, Z.M.: Carpal tunnel syndrome and bio-mechanical studies on CTS. Adv. Mech. **35**(4), 472–480 (2005). (in Chinese)
6. Michelle, Y., Cathy, S., Young, J., Colleen, D.: Human factors considerations in the design and evaluation of flight deck displays and controls. DOT/FAA/TC-16/56 (2016)
7. Federal Aviation Administration. TSO-C165A Electronic Flight Instrument. FAA (2015)
8. Civil Aviation Administration of China. CCAR-25-R4 Airworthiness Standards: Transport Category Airplanes. CAAC (2011)
9. Federal Aviation Administration. FAR Part25 Airworthiness Standards: Transport Category Airplanes. FAA (2018)
10. European Aviation Safety Agency. CS-25 Certification Specifications for Large Aeroplanes. EASA (2018)
11. ANM-11. AC25.1302-1 Installed Systems and Equipment for Use by the Flightcrew. FAA (2013)
12. ANM-11. AC25-11B Electronic Flight Displays. FAA (2014)
13. AIR-120. AC20-175 Controls for Flight Deck Systems. FAA (2011)
14. Mark, S., Ernest, J.: Human Factors in Engineering and Design (Trans. by Yu, RF, Lu, L), 7th edn. Tsing Hua University Press, Beijing (2009). (in Chinese)
15. AIR-130. AC20-138D Airworthiness Approval of Positioning and Navigation Systems (Including Change 2). FAA (2014)
16. Committee S-7. SAE ARP4102 Flight Deck Display Panels, Controls, and Displays. SAE International, Warrendale, PA (2007)
17. Radio Technical Commission for Aeronautics. DO-257A Minimum Operational Performance Standards for the Depiction of Navigation Information on Electronic Maps. RTCA (2003)
18. Radio Technical Commission for Aeronautics. Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation. RTCA (2015)
19. Federal Aviation Administration. TSO-C115D Flight Management System Using Multi-Sensor Inputs. FAA (2013)
20. International Organization for Standardization. ISO/TR 7250-2 Basic Human Body Measurements for Technological Design-Part 2: Statistical Summaries of Body Measurements from National Populations. ISO (2010)