ERGONOMIC ASSESSMENT METHOD FOR COCKPIT LAYOUT OF CIVIL AIRCRAFT X BASED ON VIRTUAL DESIGN

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Abstract

Ergonomic assessment for cockpit layout of civil aircraft (EACLCA) is very important, because awkward posture caused by illogical layout bring pilot discomfort, fatigue and misplay, which would violate aviation security and be harmful to pilot. Traditional EACLCA is field evaluation by test pilots or ergonomic experts after prototype was produced, if problems were found, modification would cost more. With the development of computer technology, EACLCA could be carried through ahead of time in virtual design phase using human model in virtual environment. Based on this, a new method for EACLCA was put forward in the paper, which supplied reference to cockpit ergonomic design, reduced the expense and developing cycle, and developed the design philosophy human-centered.

Cockpit CATIA model of civil aircraft X was imported to JACK, an ergonomic simulation and analysis software, then the model was optimized. 1%, 5%, 50%, 95%, 99% Chinese pilot human model (CPHM) were built in JACK used to EACLCA, furthermore comfort assessment model (CFAM) of EACLCA according to pilot inquirement was built, then EACLCA was carried out through main parts of cockpit such as seat, main flight panel, glareshield, rudder pedals, stick, center console, top panel and so on. Eventually some problems violating of rules of ergonomics were found, and some advices for improvement were also put forward. The result was correctly proved by field test and the method was adopted by engineer to estimate the next generation cockpit.

1 Introduction

Reasonable layout of cockpit was precondition to reducing misplay, improving safe, piloting cozily, and pledging pilot in good condition. Traditional EACLCA is field evaluation by test pilots or ergonomic experts after prototype was produced, if problems were found, modification would cost more. Ergonomic assessment based on digital model [1] could advanced EACLCA to virtual design phase, which could reduced the expense and developing cycle, and accord with the design philosophy human-centered. Early in 1960s, a workplace layout assessment method [2] based on standard work posture put forward by Wisner etc. (1963) worked well. Based on the trend of virtual assessment and the standard pilot posture, a new method for EACLCA was put forward in the paper, which supplied reference to cockpit ergonomic design.

Two major contents were included in virtual ergonomic assessment, one was aircraft digital model, and the other was accurate CPHM [3, 4]. Currently, aircraft model was mostly made in

CATIA [5, 6]. Among much ergonomic simulation and analysis software, the famous were JACK, RAMSIS, SAFEWORK, DELMIA etc. JACK consists of 69 joints, 71 segments, 135 DOF, a fully articulated hand (16 segments) and spine (17 segments) model, and vivid shoulder/clavicle joint; JACK could be manipulated to any posture expediently, hands could grasp automatically, eyes could realize vividly eyeball goggling, and JACK included many ergonomic assessment modules. So JACK was selected in the article to establish CPHM and carry through ergonomic assessment.

Cockpit CATIA model of civil aircraft X was imported to JACK and optimized. 1%, 5%, 50%, 95%, 99% CPHM were built in JACK used to EACLCA, furthermore CFAM of EACLCA according to pilot inquirement was built, then EACLCA was carried out through main equipments of cockpit such as seat, main flight panel, glareshield, rudder pedals, stick, center console and top panel. Eventually some problems violating of rules of ergonomics were found, and some advices for improvement were also put forward. Using this method EACLCA could be carry through in virtual design phase, modified in time if some problems were found, developing cycle was shorten, developing expense was reduced, design efficiency was improved. The result was correctly proved by field test and the method was adopted by engineer to estimate the next generation cockpit.

2 Import cockpit CATIA model to JACK

Traditional ergonomic assessment process was that estimator first adjusted seat in height and fore-and-aft directions to meet requirements of outer visual field, namely, estimator's glabellas was at design eyes position (DEP), and then layout of every control was assessed by manipulating himself. Assessment in the paper followed the same process: the site bottom_head.sight (Fig. 1) of JACK was positioned at DEP, and EACLCA was carried out through CPHM manipulating virtual cockpit model.

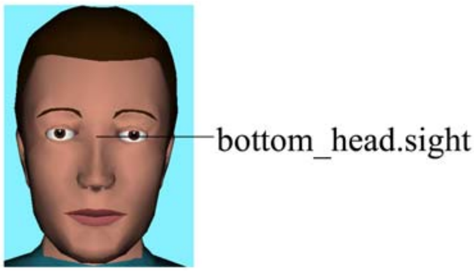

Fig. 1 The Site bottom_head.sight

*.product file of whole cockpit included DEP was saved as *.wrl file, which was imported into JACK through its import module. A *.fig file and many *.pss files were produced after importation, among which *.fig file was father file recorded information of color, joint and composing of which *.pss files, *.pss file recorded detailed information of each part composed of entity. After importation the model was more-consumed on HD space and couldn't be read in PC, optimizing must be done to satisfy the later work. Optimizing was carried out through importing *.pss file into JACK again in batches or solely by selecting different optimized parameters. Cockpit model imported to JACK was seen by replace *.pss files before importation with *.pss files after importation and open *.fig file. Optimizing made less-consumed on HD and memory space, and made ergonomic analysis possible in JACK, optimizing wouldn't affect EACLCA.

3 Building CPHM

JACK used USAF anthropometry data. American was different greatly from Chinese in physique and measurements. If Chinese cockpit was assessed with American, error would be great. Refer to GJB4856-2003[7], 1%, 5%, 50%, 95%, 99% CPHM was built used Chinese pilot anthropometry data.

First a new human model was built in JACK after inputting type (female, male or child), stature and weight in Basic Scaling module of JACK or gender and one of 26 measurements in Advanced Scaling module of JACK, or an existing human model was chosen. Then, according to Chinese pilot anthropometry data, the human model was amended in Advanced Scaling module. The 26 measurements were associated complexly, some data inputted earlier changed with the later. It was impossible that all 26 measurements used GJB data, and physique of CPHM was misshapen. For our research was ergonomics of civil cockpit, concerned anthropometry measurements were Eye Height Sitting, Abdominal Depth, Buttock-Knee Length, Knee Height Sitting, Interpupillary Distance, Bideltoid Breadth, Arm Length, Hip Breadth, Foot Breadth, Foot Length, Hand Breadth, Hand Length, and Stature as symbol of human size also was included. To make concerned anthropometry measurements using GJB data, check box before the concerned anthropometry measurements were chosen, which could hold these values invariability, other values produced by JACK.

By Advanced Scaling module concerned anthropometry measurements adopted Chinese pilot anthropometry data, but physique of CPHM may be misshapen, for example, arm was too thin, neck was too long or short, hip was too thick, thigh was too thin etc. By Body Part Scaling module of JACK size of head, neck, torso, upper arm, lower arm, hand, pelvis, upper leg, lower leg and foot could be changed to improved the physique, measurements in Advanced Scaling module would changed followed. Again we returned to Advanced Scaling module, first check box before concerned anthropometry measurements was chosen and then changed to GJB data, physique of CPHM would improve. If the physique need further improve, again Body Part Scaling module was used, again and again, until concerned anthropometry measurements of ultimate CPHM used Chinese pilot anthropometry data, and his physique was fine. Ultimate CPHM (Fig. 2) applied to EACLCA.

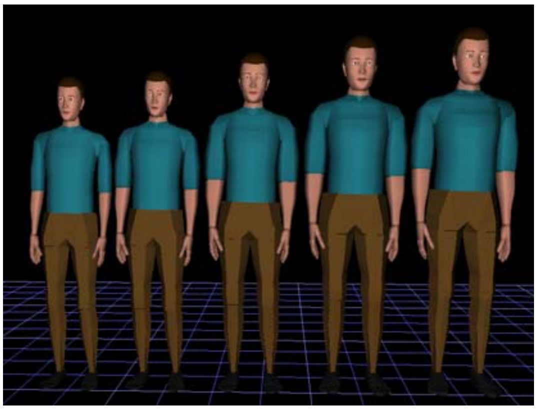

Fig. 2 1%, 5%, 50%, 95%, 99% CPHM

4 Creation of CFAM

Develop of civil cockpit went through instrumental, glass, to workstation one [8], layout of which changed greatly, the design philosophy human-centered made comfort more important. There were 6 CFAMs in JACK: Porter (1998) [9], Krist (1994), Grandijean(1980) [10], Rebiffe(1969) [11], Dreyfuss(2D and 3D) [12], which adapted to general comfort assessment for seated-posture work and car driving. Aircraft pilot was different from which in coax, knee, and anklebone joints etc., CFAM of EACLCA must be rebuilt. Dreyfuss 3D was chosen as initialization of CFAM of EACLCA since there were most joints in it compared with other models.

12 joint angles (Fig. 3) were chosen, their comfort range and most comfort value were gained through inquiring 5 civil pilots flying Boeing aircraft. Most comfort value was decided on best pilot posture when stick and rudders were neutral position, and their journeys were considered. CFAM of EACLCA was gained through changing values of 12 joint angles among Dreyfuss 3D to dates of table 1, other values unaltered.

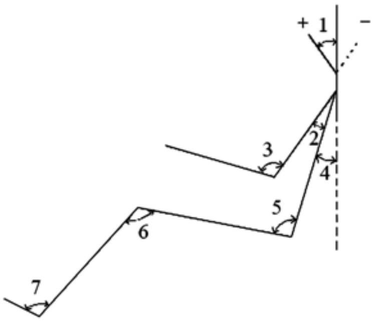

Fig. 3 Definition of Joint Angle

number	minimum /°	maximum /°	Most comfort value /°
1	−30	13	5
2	−15	35	10
3	80	120	100
4	10	25	13
5	65	120	100
6	120	160	140
7	85	120	100

Table 1 comfort range and most comfort value of 12 joint angles

Most comfortable pilot posture (MCPP) (Fig. 4) for EACLCA was built according to most comfort joint angle of CFAM for EACLCA. Which used to assessment whether Neutral position and adjusting range of seat make all CPHMs have optimal visual field, whether position of stick and rudder pedals make all CPHMs control aircraft comfortable.

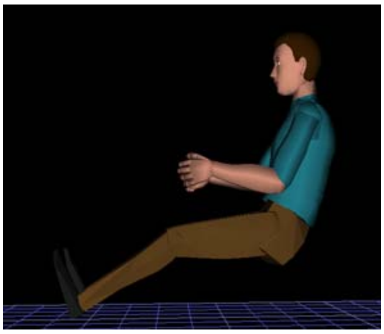

Fig. 4 MCPP for EACLCA

5 EACLCA

EACLCA was carried out through by CPHM controlling civil aircraft in cockpit model, with site bottom_head.sight at DEP. There were two kinds of pilot postures, one was cruise posture relaxed, according to which DEP was determined; the other was flying-off and landing posture, shoulder of pilot leaned closer to backrest and head closer to headrest compared with cruise posture, so bottom_head.sight wasn't at DEP, position and posture of stern and lumbar were same as cruise posture. EACLCA used one of these two postures according to different instance. Coordinate axes in JACK was: upper +y, forward +z, leftward +x, detailed estimate items as follows:

5.1 Seat

To meet outer visual field and comfort of different percent pilot, fore-and-aft and altitudinal direction of seat were adjustable, to moderate stature pilot adjust was almost needless, to small pilot seat should adjusted forward and upward, to big pilot seat should adjusted backward and downward. Neutral position and adjusting range of seat were assessed by MCPP.

According to principles of ergonomics, the adjustable products should be usable by human between 5% and 95% expediently. 5%, 50% and 95% CPHM were set as MCPP, bottom_head.sight was at DEP. Vertical distance y and fore-and-aft distance z between Lower_torso.proximal (bottom of chine or coccyx) of CPHM and center site of seat face when it was uppermost and backmost, neutral, downmost and foremost were measured, see table 2. It was obvious that neutral position on the high and back side, should amend downward 2.5cm and forward 16.7cm; adjusting range in y direction: uppermost should amend downward 4.3cm, downmost should amend downward 8.2cm; adjusting range in z direction: foremost should amend forward 12.6cm, backmost should amend forward 14.8cm. After modifying the adjusting range meet requirements of outer visual field and comfort for all pilots.

	5①	50②	95③
y（cm）	-4.3④	-2.5	-8.2
z（cm）	12.6	16.7	14.8

Table 2 value of y and z

Notice：

①: Seat locate upperpmost and backmost position

②: Seat locate neutral position

③: Seat locate bottommost and foremost position

④: - denote that Lower_torso.proximal located under of center site of seat face

Width and depth of seat face, room between seat and stick, main flight panel, and glareshield could accommodate 99% CPHM completely.

5.2 Main flight panel and glareshield

Main problems of these two devices were inner visual field. CPHM of different percent were at same DEP, so assessment was carried out only to 50% CPHM.

It's prescribed in AC NO: 25.773-1[13]: Forward and down inclination from the horizontal datum plane between 30 degrees left and 10 degrees right of the vertical datum plane shouldn't less than 17 degrees. The inclination was 20 degree when bottommost edge of windscreen was observed, which met the standard completely.

It prescribed in the standard MIL-STD-1472F [14]: Normal Line of Sight was down 15 degrees from Horizontal Line of Sight; vertical visual field was prescribed down 35 degrees and up 65 degrees from Normal Line of Sight when head could rotation. That is, up 50 degrees to down 50 degrees from Horizontal Line of Sight was in better visual field for pilot. Inclination between line of sight for lowest edge of panel and Horizontal Line of Sight was 45 degrees, which met the standard completely.

Controls on glarefield were inside reach zone of 1% CPHM whose posture was cruise or flying-off and landing one.

5.3 Rudder pedals

1% and 99% CPHMs were as boundary because it could cause serious aftereffect if rudders were outside reach zone. Pedals should be located in neutral position when 50% CPHM controlled it, backmost position when 1% CPHM controlling, foremost position when 99% CPHM controlling. Assessment results seen table 3. Neutral position of redder pedals were appropriate, adjusting range should be changed, foremost position should amend backward 14cm, downward 3cm; backmost position should not changed, because

control manner	assessment result		
	1%	50%	99%
control under MCPP	pedals was backward 3cm and downward 5cm; shinbone contacted lowest edge of panel	pedals was MCPP position; shortest distance between shinbone and lowest edge of panel was 5cm	pedals was forward 14cm and upward 3cm; shortest distance between shinbone and lowest edge of panel was 7cm
control under present layout	joint of coax, knee and ankle were inside of comfort range, shortest distance between shinbone and lowest edge of panel was 5cm	joint of coax, knee and ankle were MCPP	couldn't reach

Table 3 layout assessment result of rudder pedals shinbone of 1% CPHM contacted lowest edge of panel (Fig. 5) if he controlled pedals using MCPP. For height of panel couldn’t change random, pedals couldn’t be controlled using MCPP, design layout was reserved, room between shinbone and lowest edge of panel was assured, comfort was reduced, but joint of coax, knee and anklebone were located in comfortable range. CPHMs outside 50% were inside comfortable range after amendment when controlling pedals.

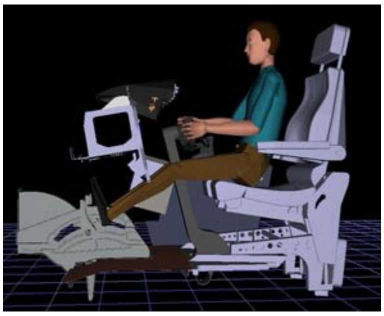

Fig. 5 Shinbone of 1% CPHM Contacted Lowest Edge of Panel

5.4 Stick

If stick located out of the way, some problems were caused such as journey was added, abdomen was extruded, the upper arm was discomfort etc., and its height also affected inner visual field. Because DEP of all CPHMs were same, only 50% CPHM was analyzed. It found that inner visual field hadn’t affected by stick from eye view (Fig. 6) of 50% CPHM.

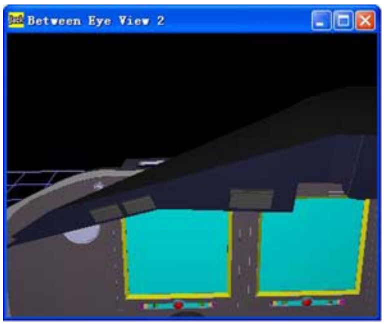

Fig. 6 Eye View of 50％ CPHM

When CPHM controlling stick using MCPP, for 95% CPHM stick was at most comfort position; for 50% CPHM stick was about 2.0cm forward and 2.8cm downward from most comfort position; for 5% CPHM stick was about 3.5cm forward and 6.0cm downward form most comfort position. Presently stick wasn’t adjustable, it should be amended 2.8cm upward and 2.0cm backward so as to its neutral position make 50% CPHM using MCPP. After amendment joints of upper arms were inside comfort range when 5% and 95% CPHMs controlled stick, and height of stick hadn’t affected inner visual field.

5.5 Center console

Center console located right of first pilot, its primary controlling devices included throttle, grip brake etc. When throttle was controlled by 50% CPHM, wrist ulnar deviation was beyond 33.4° from comfort range; 36.8° for 5%; 28.3° for 95%. That caused by position, shape and journey of throttle. Controlling period shouldn’t keep long when wrist ulnar deviation was large, otherwise discomfort would arose, even wrist would ache, then disease of wrist would happen [15, 16, 17]. It would improved by changing shape and/or position of throttle, such as changing throttle to palm facing body.

Throttle was at middle of center console, two key controls left and right of throttle weren’t intervene by simulation. Wrist ulnar deviation was more serious for right control. For steering period was short and frequency was few, to these two controls comfort shouldn’t be emphasized extremely.

To other controls, reach ability of 1% CPHM was analysis. By reach zone under cruise posture top right corner of forepart controlled by first pilot couldn’t be reached, needed CPHM bow forward. If aiguillette was locked, controls couldn’t be reached would more.

5.6 Top panel

Top panel was few controlled, reachability and visibility of 1% CPHM, and accommodation ability of 99% CPHM were analyzed. To visibility, all controls could be seen when 1% CPHM flexed neck backward, flexion angle was -18°, inside comfort range. To reachability only 1/3 of whole top panel could be reached under cruise posture (Fig. 7) for 1% CPHM, even to 99% CPHM rear part of top panel also couldn't be reached under any seat postures. To accommodation ability, enough head room existed for 99% CPHM. To improving reachability, we suggested shape of top panel be changed to arc and near reach zone of 1% CPHM, and head room should be enough to 99% CPHM.

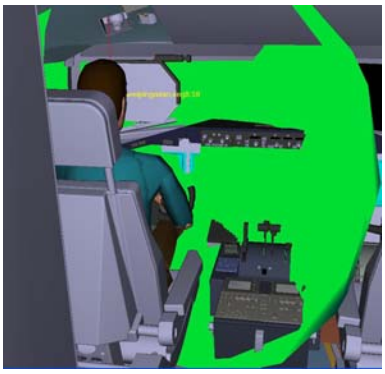

Fig. 7 Reach Zone of 1% CPHM

6. Conclusion

Reasonable layout of cockpit was precondition to reducing misplay, improving safe, piloting cozily, and pledging pilot in good condition. So EACLCA was all-important. According to field assessment, first estimator adjusted seat to meet outer visual field requirements; then assessment was carried out through CPHM manipulating the virtual cockpit. X civil cockpit was assessed by simulating, some problems violating of rules of ergonomics were found. For example, neutral position of seat was backward and upward, adjustment in height was upward, adjustment in fore-and-aft was backward. Neutral position of redder pedals were appropriate, adjusting range should be changed, foremost position should amend backward and downward; backmost position should not changed for shinbone of 1% CPHM contacted lowest edge of panel when he controlled pedals using MCPP. For height of panel couldn't be changed, pedals couldn't be controlled using MCPP, backmost position was reserved, room between shinbone and lowest edge of panel was assured, comfort was reduced, but joint of coax, knee and anklebone were located in comfortable range. Stick was foreword and downward, which affected comfort. Wrist was discomfort when controlling throttle. Top panel couldn't be reached completely and so on. The result was correctly proved by field test.

It would cost more to modify if prototype of cockpit with these problems was built. So EACLCA was necessary in virtual design phase. The method for EACLCA put forward in the paper could run in PC and was adopted by engineer to estimate the next generation cockpit, supplied reference to cockpit ergonomic design, reduced the expense and developing cycle, and developed the design philosophy human-centered, also it could be developed in many fields, such as layout of flight panel interface and button of control platform, all of which will increase efficiency of design and meet the design philosophy human-centered much more.

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