Research on Error Proofing Design of Boeing and Airbus Cockpit from Pilots Survey

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Abstract. Human errors are main causes of most aircraft accidents. Fighting on human errors is important mission of aircraft designer as well as pilot and air traffic controller. Error proofing design for controls in aircraft cockpit is one of the design goals of ergonomics. According to human error management for flight crew, the error proofing design methods are established. A questionnaire which was composed of 25 closed-ended questions were designed for collecting the pilot view. The questionnaire was tested from two respects of reliability and validity. 125 valid questionnaires were collected altogether. The analysis is divided into two parts: the degree of safety support and the frequency. Then by analyzing data from each question, including mean and variance of Boeing and Airbus, the paper studies on the differences and similarities between Boeing and Airbus aircraft in error proofing design. It studies the reasons for the different efforts of error proofing design between Boeing and Airbus aircraft. The paper also considers the effects of pilots' age on every question. Regression analysis is used for analyzing the variation tendency with age. The result is that pilots consider that the design in Boeing cockpit has superior maneuverability while design in Airbus cockpit do better in logical protection than Boeing. The paper provides a reference for the study of error proofing design in the cockpit.

Keywords: Human error · Error proofing design · Reliability · Validity

1 Introduction

It is necessary to pay attention to safety of civil aviation. With the development of technology, science and material, civil aviation safety has been in good condition. However, civil aviation accidents still occur. Statistics reveal that human factors is the main cause of accidents and incidents [1]. Although human factors has been a research hotspot for decades, accidents and incidents caused by human error of flight crew happen sometimes.

In order to use human factors control methods to improve safety, analytical models are presented. HFACS (Human Factor Analysis and Classification System) was developed by Dr. Douglas Wiegmann and Dr. Scott Shappell in the United States Navy to identify why accidents happen continuously and how to reduce the accident rate. HFACS is well applied in civil aviation. Professor Elwyn Edwards proposed SHEL

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(Software Hardware Environment Liveware) model consisting of four basic elements: Software Hardware Environment Liveware [2]. Software hardware environment and liveware are foundation of good man-machine system. The four basic elements of SHEL model are not isolated; on the contrary, they are interacted with each other. Excellent man-machine interface can reduce human error effectively.

Boeing and Airbus are two renowned airliner manufacturing companies. They accept the concept that human errors can be reduced by design and their crew-centered cockpit is used widely and proved to be available for safety of civil aviation [3]. Their design concept of man-machine interface are different. Research on similarities and differences of error proofing designs between Boeing and Airbus is helpful to reduce human errors in cockpits and accomplish flight missions safely.

2 Error Proofing Design

2.1 Operation Error

Human factors theories provide basis for error classification. HFACS describes four levels of human factors: unsafe acts, preconditions for unsafe acts, unsafe supervision and organizational influences. Unsafe acts contains error and violation [4]. Errors can further be divided into three types: skill-based error, decision-based error and perceptual-based error. Another classification hold the idea that unintentional unsafe acts fall into the following categories: operation or decision error, omission, skills incapability, improper disposal of emergency, illegal violations, crew incapacitation and improper crew resource management [5].

All the above-mentioned unsafe acts has an action link and error in action link. There is deviation between operational results and the expectation. This is the connotation of the concept of operation error.

2.2 Operation Error Management

There are four management strategies for operation error as follows:

Segregation. It reduce or eliminate error by separating pilots and controls from the factors that can lead to error. It can control error directly from the source. For instance, designing physical isolation device that can prevent pilots activating control device over it [6].

Perception. Increasing pilots' real-time understanding of aircraft condition and status by designing prompt information, such as a device using visual information display its status.

Obstruction. Projecting multi-link procedures for controls. Operation of a control is designed for rotating after pulling instead of pushing exclusively.

Support. Providing physical support to improve the accuracy of the flight crew action to perform the expectation. The control device is designed to be not easy to mistakenly hit. Reducing error that comes from pilots want to operate a control device accidentally triggered a different control.

Table 1. Error proofing design methods

Method	Detail
Location & orientation	Locate, space, and orient controls so that the operator is not likely to strike or move them accidentally in the normal sequence of control movements
Physical protection	Physical obstructions can be built into the design of a control to prevent accidental actuation of the control. Examples include: recessed controls, shielded controls, flip-covers, and guards. Make physical protections so they do not interfere with the visibility or operation of the protected device or adjacent controls
Slippage resistance	The physical design and materials used for controls can reduce the likelihood of finger and hand slippage (especially in the presence of vibration)
Hand stabilization	Provide hand rests, armrests, or other physical structures as a stabilization point for the pilot's hands and fingers when they are operating a control. This can be particularly useful for controls used in the presence of turbulence and other vibration, helping the pilot make more precise inputs
Logical protection	Software-based controls and software-related controls may be disabled at times when actuation of the control would be considered inappropriate, based on logic within the software. Make disabled (inactive) controls clearly discernable from active controls
Complex movements	The method of operation for a control can be designed so that complex movement is required to actuate it. For example, a rotary knob can be designed so that it can only be turned when it is also being pulled out. Double-click or push-and-hold methods are not recommended methods of protection
Tactile cues	The surfaces of different controls can have different shapes and textures, supporting the pilot in distinguishing different controls when operating in a dark or otherwise "eyes free" environment
Locked/interlocked controls	Locking mechanisms, interlocks, or the prior operation of a related control can prevent inadvertent operation. For example, a separate on/off control can activate/deactivate a critical control, or physically lock it in place
Sequential movements	Controls can be designed with locks, detents, or other mechanisms to prevent the control from passing directly through a sequence of movements. This method is useful when strict sequential actuation is necessary
Motion resistance	Controls can be designed with resistance (e.g., friction, spring, inertia) so that deliberate effort is required for actuation. When this method is employed, the level of resistance cannot exceed the minimum physical strength capabilities for the intended pilot population
Tips indication	Pilots should be provided with current state of controls by one or more auditory cues, tactile cues, or visual cues. As a general rule, the greater the consequence of an unintended operation, the more salient the cues that should be provided. Controls should clearly indicate which areas of the electronic display are active for control functionality. Provide a means to reverse an incorrect activation or input, when appropriate

2.3 Error Proofing Design Methods

Refer to FAA advisory circular No. 20-175, which provides guidance for the installation and airworthiness approval of flight deck system control devices, from primarily a human factors perspective, establish 11 kinds of error proofing design methods for traditional dedicated controls and multifunction controls in Table 1 based on operation error management strategies [7].

3 Questionnaire's Design

3.1 Structure of Questionnaire

Questionnaire is a set of designed questions form and begins from making clear research purpose of the survey, which is assessment of the error proofing design of airliners of Boeing and Airbus. Respondents of the survey are pilots on active duty who drive Boeing and Airbus aircrafts in civil aviation.

Structure of questionnaire contains four parts: title, cover letter, instruction and questions. Title describes content of the survey to respondents so that they can have a general understanding of the investigation. The paper use "Questionnaire of error proofing design of civil aviation aircraft cockpit for reducing operation error" as its title to allow pilots be familiar with it because it is work-related.

Cover letter shows purpose of the survey to pilots and explain this is an anonymous survey and just for academic research.

Instruction is provided to explain how to answer questions, including issues explanation and illustration of questionnaire. Instruction is helpful to respondents for filling in the answer, and to some extent it can affect the quality of the recovered questionnaires.

The last part of questionnaire is questions.

3.2 Question's Design

Questions are used to assess error proofing design in aircraft cockpit. In order to evaluate objectively, all the questions are designed in the same form. Every question is divided into two aspects: the degree of safety support and frequency. The degree of safety support represents error proofing design is helpful for safety and need respondents evaluate the extent of the help. Frequency means the rate of operation error without the error proofing design. Each aspect has five levels, from 1 to 5, which is established by referring Likert scale. For the degree of safety support, level 1 means few support for flight safety and as the levels increase, increased support for flight safety; level 5 expresses great support for flight safety. Like the degree of safety support, 1 to 5 levels of the frequency represent the operation error frequency from never, hardly, sometimes, often to always. In the following, Variable S is used to on behalf of the degree of safety support and variable F means the frequency.

For frequency, the question formulation becomes to the operation error frequency without error proofing design. The reason is that for some questions the operation error frequency is unknowable, such as questions carry logical protection method; because of logical protection, pilots operate the control will not make errors, so there is no the rate of operation error. For the above reasons, the questionnaire choice operation error frequency without error proofing design as one aspect.

Questions are designed and project team went to Air China to have interviews with pilots four times. First time, asking whether questions are matched with the actual situation or not and modifying questions according to actual situation. Second time, discussing with pilots how to reduce operation error. Talk about crew resource management, regulations, training, standard operation procedure and then pay attention to preventing operation error by error proofing design of controls. Third time, requesting pilots help to make the modified questionnaire clearly and easy to understand and answer. Last time was for questionnaire test; the team got questionnaire tested and feedbacks from 15 pilots. 15 questionnaires were hand put and responded.

The final questionnaire contains 25 closed-ended questions as shown in Table 2. It should be noted that each question has two aspect like question 1.S means the support for safety and F represents frequency of making corresponding operation error without the error proofing design. Questions covered all the 11 kinds of error proofing design methods.

Table 2. Questions

1	Engine and APU fire control panel includes control buttons, indicator and test button, in order to avoid misuse, the control buttons designed with a protective cover. (1) How much help do you think that the protective cover ensure flight safely? (2) Without the protective cover, how often do you think that you will make error when you operating the control button?
2	Gear lever has two stalls, there is landing gear position indicator show the current status of the landing gear [8]
3	When “speed > 260”, the Airbus aircraft landing gear lever is unable to make gear down; Boeing aircraft landing gear can be released, but there are voice prompts
4	Airbus airplane has been designed with “αFLOOR protection and when speed is less than the protection speed, the plane will make a full throttle automatically ignoring the throttle lever movement from pilot; Boeing airliner has not αFLOOR protection
5	Airbus aircraft pilot operation have boundaries and pilot can’t override them; Boeing pilot can control airliner do some action out of gauge in emergency situations. For example: when the Airbus airliner slope between 33°–67°, manipulation must continue to allow the aircraft to maintain current state, and aircraft slope will not exceed 67° even if the side stick is on the maximum position; while Boeing pilot can do operation of the aircraft slope overrun exceeds 67°
6	Boeing aircraft designed with throttle lever following with the A/t (auto-throttle), while Airbus airliner does not have throttle lever follow with the A/t. A/t disconnect of Airbus airliner is designed to pull the throttle lever back to EPR position, then disconnect the A/t
7	External lighting system control panel contain switches of anti-collision light, wing light, range lights, landing light, strobe light and so on. These switches are designed with different shapes and texture to avoid misuse [9]

(*Continued*)

Table 2. (*Continued*)

8	Steering tiller is designed with curved surface to prevent hand slippage when pilot operate it
9	Flap lever has 5 stalls and each stall can be sequentially moved to another, i.e., 0↔1, 1↔2, 2↔3, 3↔4 shift change is permitted, 1↔3, 4↔2 change must be pressed down in the middle of the stalls to move to the next position
10	Stabilizer trim switch is tight and need to be pushed hard
11	Engine start control knob is shaped to fit two fingers to grip the operation, not easily slip through fingers
12	There are indicator lights shows the priority and the current state of joystick/side stick in front of the captain and first officer, reminding pilot who control the aircraft
13	Flap lever has five stalls, the choice of any stall is first lift the handle and then hanging on
14	Automatic thrust release button is in the inside of throttle lever and not easy to mistakenly touch; pilot can lift the automatic thrust by pressing the button
15	Flight Control Unit (FCU), which has four selection buttons: speed/Mach select button, heading/track select button, height select button, lift rate/flight path angle select button. The shape, size and surface of these four buttons are different to increase their degree of differentiation to prevent misuse [10]
16	Reverse thrust lever is mechanically locked in the collection position. Lifting reverse thrust lever to the chain a little bit and keep until the chain unlock, and then use reverser thrust according to the demand
17	Reverser thrust lever has slot/card at position with 70 % reverser thrust, there is a sense of a card when the reverse thrust lever move to that location
18	Retracting reverse thrust lever operation is pressing after forward movement of the handle
19	When the aircraft is approach to the stall, black and red stripes will be showed below the stall warning of speed marker of Primary Flight Display (PFD) [11]
20	Stabilizer trim wheel operation can only move back and forth, and it is not easy to change its position when pilot mistakenly hit it
21	The emergency power control panel has manual button and emergency generator test button, and they are provided with protective cover
22	After the landing gear control failure, pilot can use free fall extension handle to put the gear down. Free fall extension handle is chain multi-positional selector, by an interlocking device that can be connected together. When link disengaged, each selector can be operated solely
23	Park brake selector need to lift the handle operation, and then turned to the ON or OFF position
24	Auto brake control panel can be adjusted "RTO, MAX or other stalls" button to select a stall and it is a little tight when you shift
25	Joystick has an arcuate recess to help to increase stability of grip by thumb

3.3 Questionnaire Distribution

The targets of the survey pilots who drive civil airliners. In order to avoid pilots belong to same regional and same airline pilots producing a specific effect on the survey results, the paper choice three airlines to investigate [12]. They are Air China, the Spring Airlines and the Okay Airways Company Limited.

Air China is the head of airlines of China. By the end of September 2014, Air China and its subsidiaries have 532 various types of passenger airliners and cargo aircrafts with Boeing and Airbus aircraft dominated. Therefore, Air China has been the main target of investigation. Spring Airlines is a famous budget airline in China.

50 questionnaires were distributed to Beijing Branch of Air China and 43 ones were got back; 30 questionnaires handed out to Tianjin Branch of Air China and 23 ones were recovered; 50 questionnaires were sent to the Spring Airlines and 45 questionnaires were taken back; 30 questionnaires were granted to the Okay Airways Company Limited and 24 ones were got back. Questionnaire completed more than eighty percent is identified valid questionnaires. 125 out of 135 collected questionnaires are valid. The valid callback rate is 92.59 %.

4 Reliability and Validity Analysis

4.1 Pilots Personal Characteristics Analysis

Questionnaires collect data from a total of 125 pilots, 70 driving aircrafts of Boeing and 55 for airliners of Airbus. Statistical results of their driving experience and age are shown in Tables 3 and 4. Driving experience is divided into five groups (below one year, more than one year and less than three years, more than three years and less than five years, more than five years and less than ten years, more than ten years) according to driving years. Every driving experience group has similar amount of pilots, so that single driving experience group will not affect the analysis specifically.

Table 3. Statistical results of driving experience

Driving experience	Boeing	Airbus	Total
Below one year	10	9	19
More than one year and less than three years	13	13	26
More than three years and less than five years	11	8	19
More than five years and less than ten years	12	8	20
More than ten years	24	17	41

Table 4. Statistical results of age and technical grade

Age	Boeing	Airbus	Total	Technical grade	Boeing	Airbus	Total
20–29	23	21	44	Copilot	34	23	57
30–39	25	20	45	Caption	19	13	32
40–49	16	12	28	Instructor	17	19	36
50–59	6	2	8				

Age is divided into four categories: 20–29 years old, 30–39 years old, 40–49 years old and 50–59 years old. From Table 3, it can be seen that the number of pilots with different age groups are similar except age between 50 and 59 years old (they are too old to be competent to flying work). The number of pilots between 50 and 50 years old is short and this is consistent with the fact. Expect for the oldest group, the pilots' age distribution are relatively uniform for the rest.

Statistical Results of Technical Grade of pilots are shown in Table 4. There are three technical grade: copilot, caption and instructor. The number of copilot, caption and instructor are similar. The number of copilot is most and this is consistent with the reality.

4.2 Reliability Analysis

Reliability is used to describe the degree of consistency of the results of survey and measure the reliable level of the results of survey [13]. In this paper, Cronbach's α is used for homogeneity reliability test provided by SPSS software and the test results of reliability test of degree of safety support and frequency as shown in Table 5.

Table 5. Homogeneity reliability test (Cronbach's α)

Variable	Boeing	Airbus	Number of items
S	0.880	0.784	25
F	0.909	0.894	25

For *S*, Cronbach's α of Boeing is 0.88; for *F*, Cronbach's α of Boeing and Airbus are 0.909 and 0.894. They all more than 0.8, supporting good reliability. Cronbach's α of Airbus for *S* is 0.784 and this is a general reliability test result. Therefore, it is accepted that results of the survey is reliable and credible.

4.3 Validity Analysis

Validity reflects the degree of effectiveness of measurement results. Factor analysis is applied for validity test of the questionnaire [14]. There is a prerequisite for factor analysis, which is the correlation between the original variables. Kaiser-Meyer-Olkin test is used for verifying the correlation between variables and Bartlett's test is applied for checking out variables are mutually independent.

KMO and Bartlett's test as shown in Table 6. The KMO test value of degree of safety support is 0.738 greater than 0.7; the Bartlett's test probability is 0.000, less than 0.05 significance level; illustrating factor analysis can be used to test the validity. Factor analysis giving the percentage of accumulated contribution of variances of *S* is 63.933 %. The KMO test value of frequency is 0.755 greater than 0.7; the Bartlett's test probability is 0.000, less than significance level of 0.05; illustrating factor analysis can be used to test the validity. Factor analysis giving the percentage of accumulated contribution of variances of *F* is 65.712 %. Showing that the questionnaire has good construct validity.

Table 6. KMO and Bartlett's test

	Kaiser-Meyer-Olkin measure of sampling adequacy	Bartlett's test of sphericity		
		Approx. chi-square	df	Sig.
S (degree of safety support)	0.738	1121.587	300	0.000
F (frequency)	0.755	1286.689	136	0.000

After reliability and validity analysis, making clear that the questionnaire results are reliable and further analysis can be started.

5 Data Analysis

5.1 Data Analysis of *S*

The data was analyzed by SPSS [15]. Statistical results of *S* are showed in Table 7.

Table 7. Statistical results of $S(\bar{x} \pm s)$

Question	All pilots	Boeing	Airbus
1	4.38 ± 1.39	4.09 ± 2.02	4.76 ± 0.34
2	4.58 ± 0.71	4.62 ± 0.79	4.53 ± 0.61
3	4.03 ± 1.02	3.83 ± 1.25	4.29 ± 0.61
4	3.92 ± 0.95	3.67 ± 1.09	4.25 ± 0.59
5	3.71 ± 1.07	3.44 ± 1.11	4.06 ± 0.82
6	3.91 ± 1.27	4.17 ± 1.25	3.59 ± 1.13
7	3.36 ± 1.54	3.55 ± 1.79	3.12 ± 1.15
8	4.18 ± 0.72	4.18 ± 0.67	4.18 ± 0.79
9	4.43 ± 0.54	4.32 ± 0.59	4.57 ± 0.45
10	3.75 ± 0.74	3.76 ± 0.71	3.75 ± 0.79
11	3.98 ± 0.98	3.88 ± 1.00	4.12 ± 0.95
12	3.90 ± 0.99	3.73 ± 1.09	4.12 ± 0.78
13	4.61 ± 0.41	4.52 ± 0.53	4.73 ± 0.24
14	4.11 ± 0.98	4.03 ± 1.11	4.22 ± 0.81
15	3.85 ± 1.07	3.91 ± 1.16	3.78 ± 0.97
16	4.49 ± 0.49	4.44 ± 0.53	4.55 ± 0.45
17	3.94 ± 0.99	3.88 ± 1.00	4.02 ± 0.98
18	3.78 ± 1.21	3.50 ± 1.42	4.14 ± 0.72
19	4.31 ± 0.87	4.21 ± 1.09	4.43 ± 0.57
20	3.87 ± 1.13	3.79 ± 1.09	3.98 ± 1.18
21	4.29 ± 0.64	4.06 ± 0.73	4.59 ± 0.37
22	4.19 ± 0.96	4.08 ± 1.21	4.33 ± 0.63
23	4.11 ± 1.29	3.80 ± 1.36	4.51 ± 0.94
24	3.43 ± 1.33	3.45 ± 1.36	3.39 ± 1.32
25	3.62 ± 1.22	3.76 ± 1.23	3.45 ± 1.17

For S, evaluation of questions are all greater than 3. Among the 25 questions, the first three highest evaluation values are question 2, 13 and 16. Pilots consider the error proofing designs of these three questions are important to flight safety. Question 13 has the highest value of these questions, supporting the idea that pilots pay attention to flap lever and complex movement design of flap lever can improve safety. Question 16 is about the locked/interlocked reverse thrust lever design, which is evaluated highly by pilots. Question 2 has high value, presenting that pilots attach importance to landing gear position indicator. Pilots' opinions on these three questions are focused.

Question 7 has the lowest evaluation value and maximum variance, which means that tactile cues of the buttons are less helpful to support flight safety for pilots and pilots' views on this question are scattered.

Evaluation values of question 1, 3, 8, 9, 14, 21, 22 and 23 are also greater than 4. For question 1, mean of S of Boeing is less than Airbus and variance of S of Boeing is greater than Airbus. Question 1 consider the protective cover of fire control button, it can be seen that pilots view on the protective cover are different between Boeing and Airbus and Boeing pilots have dispersed opinions while Airbus pilots give concentrated comments. Question 21 is also about protective cover design, the high average value of question 1 and 21 showing that pilots think they can support flight safety effectively. Question 8, 9 and 14 got high evaluation average and pilots' advice is focused. Question 3, 22 and 23 also have high means while their variances are greater than question 8, 9 and 14, showing that pilots may have different opinions.

Question 13 and 23 belong to complex movements and their high evaluation values mean that pilots think this error proofing design method can support flight safety greatly.

Pilots' views on question 1, 6, 7, 23, 24 and 25 are scattered, this can be seen by their large variance and pilots may have different opinions on these questions.

Means of Boeing approximately equal to Airbus and variances of Boeing approximately equal to Airbus are question 2, 8, 10, 16, 17, 24. Pilots of Boeing and Airbus on these questions have similar points. Question 12, 13, 18, 19, 21, 22 and 23 present mean of Boeing less than Airbus and variance of Boeing greater than Airbus. Compared to Boeing pilots, Airbus pilots have higher evaluation values and less volatile on these questions.

For question 3, 4 and 5, mean of S of Boeing is less than Airbus and variance of S of Boeing is greater than Airbus. These three questions belong to logical protection, Airbus pilots pay more attention to these logical protection designs and it is clear that they all agree that it is very important for flight safety. Boeing pilots' evaluation values on question 3, 4 and 5 are less than Airbus pilots and larger variances indicating that some of them think these logical protection designs are important to flight safety while others do not think these logical protection designs can support flight safety effectively.

5.2 Data Analysis of *F*

Statistical results of F are showed in Table 8.

For F, it can be seen that averages of questions are between 2 and 4. Among questions, the first three highest evaluation values are question 6, 9 and 13.

Table 8. Statistical results of $F(\bar{x} \pm s)$

Question	All pilots	Boeing	Airbus
1	2.97 ± 1.25	2.73 ± 1.25	3.29 ± 1.09
2	3.23 ± 1.45	3.35 ± 1.55	3.08 ± 1.31
3	2.74 ± 1.45	2.42 ± 1.32	3.16 ± 1.34
4	2.68 ± 0.89	2.53 ± 0.93	2.88 ± 0.79
5	2.56 ± 0.83	2.36 ± 0.57	2.82 ± 1.07
6	3.75 ± 1.34	4.21 ± 0.91	3.16 ± 1.29
7	2.55 ± 1.11	2.61 ± 1.07	2.47 ± 1.17
8	2.99 ± 1.06	2.98 ± 1.09	3.00 ± 1.04
9	3.58 ± 1.07	3.35 ± 1.09	3.88 ± 0.906
10	3.26 ± 1.01	3.09 ± .097	3.49 ± 0.97
11	3.06 ± 1.26	2.91 ± 1.19	3.25 ± 1.31
12	3.33 ± 0.93	3.27 ± 0.88	3.41 ± 1.01
13	3.99 ± 0.91	3.94 ± 1.01	4.06 ± 0.78
14	3.38 ± 1.20	3.29 ± 1.28	3.49 ± 1.10
15	3.10 ± 1.44	3.14 ± 1.17	3.06 ± 1.82
16	3.55 ± 0.99	3.58 ± 0.93	3.51 ± 1.09
17	3.54 ± 1.22	3.38 ± 1.04	3.75 ± 1.39
18	3.15 ± 1.19	2.95 ± 1.31	3.39 ± 0.96
19	3.33 ± 1.40	3.24 ± 1.57	3.45 ± 1.17
20	3.26 ± 1.35	3.18 ± 1.51	3.37 ± 1.16
21	3.24 ± 1.43	3.20 ± 1.21	3.29 ± 1.73
22	3.09 ± 1.35	3.18 ± 1.69	2.98 ± 0.90
23	3.45 ± 1.15	3.17 ± 1.22	3.82 ± 0.83
24	2.86 ± 1.26	2.89 ± 1.36	2.82 ± 1.15
25	2.79 ± 1.44	3.11 ± 1.48	2.39 ± 1.12

Pilots consider the error proofing designs of these three questions can reduce their operation error. Question 6 is belongs to tips indication and has the highest mean of all the question, which indicating pilots think that throttle lever movement can help them clear aircraft state to keep error away effectively. And showing that pilots hold the idea that throttle lever following with the A/t can often remind them of aircraft status to reduce errors further. Question 9 and 13 consider flap lever and question 16 and 17 care about reverser thrust lever; pilots also hold the idea that error proofing design of flap lever and reverser thrust lever can reduce error effectively. Therefore, these questions get high evaluation means.

Question 13 and 23 belong to complex movements and their high evaluation values supporting that pilots hold the idea that this error proofing design method can reduce their operation error effectively.

Pilots' views on question 2, 3, 15, 19, 21 and 25 are scattered, this can be seen by their large variance and pilots may have different opinions on these questions. Question 3 belong to logical protection, pilots have different views on its design maybe is because some pilots have less practice in such cases in actual work. In addition, during flight mission, it is not easy to make gear down with high speed for them. Logical protection contains question 3, 4 and 5, evaluation values of these three questions are small, which illustrating that pilots consider that their demands for logical protection to reduce error compared with other error proofing design methods.

Among the 25 questions, variances of question 2, 10, 12, 14, 17, 19, 20 and 23 are also greater than 3.2, which means related error design proofing can support flight safety and can prevent operation error. This is why they get high evaluation averages.

Through the above analysis it can be seen that flap lever and reverser thrust lever are closely related to flight safety and it is necessary to carry out error proofing design of them.

In addition, pilots' demand for error proofing design may decrease with their increasing age for some questions and may also exhibit different changes. For instance, Boeing pilots with different ages have different points on question 21 for F. Regression analysis are used for finding the trends. By regression analyzing of question 21 as shown in Fig. 1, with age increasing, the evaluation mean firstly decreases and then increases. Young pilots may often need error proofing design to prevent error and after age increased they are not easy error and further into old age comes with declining in physical function making them take their demand of error proofing design into consideration.

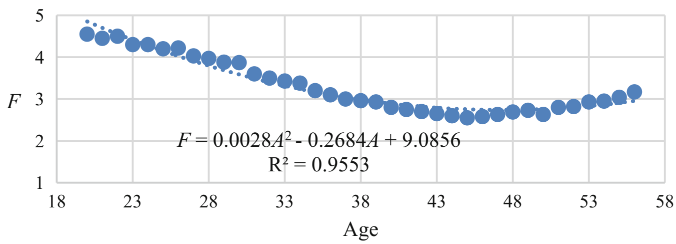

Fig. 1. Regression analysis of question 21 of Boeing

6 Conclusion

Error proofing design of controls in civil aircraft cockpit has important significance to reduce operation error of pilots. For a control, several error proofing design methods may be used in design and these applications can effectively reduce operation error of the pilots in actual. Analysis of the questionnaire results showed that:

The 11 kinds of error proofing design methods have different importance, the method with isolation strategy has significant effect on preventing error, such as physical protection and logical protection. From pilots' attitude, it can be seen that complex movements, physical protection and tips indication are the most effective error proofing design methods.

In the application of 11 kinds of error proofing design methods, Boeing doing better in motion resistance, hand stabilization and its error proofing design based on good maneuverability; Airbus well work in logical protection, which proved their point that flight mission completed by collaboration of automation and flight crew as the managers.

The error proofing design of controls should take different characteristics pilots into consideration. With increasing age, their demands for error proofing design of different controls exhibit different trends.

For full consideration, both Boeing and Airbus manufacturer's design can only represent the mainstream of design, and not represent all of the current design; therefore, further comprehensive researches are required.

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