Usability Evaluation Survey for Identifying Design Issues in Civil Flight Deck

Negin Ozve Aminian, Fairuz Izzuddin Romli and Surjatin Wiriaidjaja

Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

negin_oa@yahoo.com

Abstract. Ergonomics assessment for cockpit in civil aircraft is important as the pilots spend most of their time during flight on the seating posture imposed by its design. The improper seat design can cause discomfort and pain, which will disturb the pilot's concentration in flight. From a conducted survey, it is found that there are some issues regarding the current cockpit design. This study aims to highlight potential mismatches between the current cockpit design and the ergonomic design recommendations for anthropometric dimensions and seat design, which could be the roots of the problems faced by the pilots in the cockpit.

1. Introduction

Flight deck is the place where the pilots control the aircraft during different flight phases. Since flight safety is of paramount importance, good physical and psychological conditions of the pilots are critical issues that have to be maintained by means of, among other things, proper design of cockpit’s facilities and navigational instruments. An aircraft is a large class of systems that require active interaction or continuous control by the pilot, thus the cockpit design must address the inherent sensing and reaction capabilities of pilots as a critical constraint. This is in addition to a range of associated human-machine interfaces such as design and placement of controls, displays and seat position.

Human factors and ergonomics, which has also been known as comfort, functional or user-friendly system design, is the practice of designing products, systems or processes that takes proper account on the interaction between them and the people who are intended to use them. This particular field has been developed significantly through contributions from many other disciplines. Basically, designing products or systems that are concerned with human factors and ergonomics follow two main goals: the health and also the productivity of the people who use them. A good ergonomic design is concerned with the ‘fit’ between user and their technological tools [1]. With regards to the cockpit design, a good interface design enables the pilots to easily access all the required control panels in any situations.

The feeling of discomfort and low back pain complaints during flights have been reported by pilots around the world each year. During a long flight or flying in improper physical conditions, a pilot may feel easily fatigue and stressed due to many possible reasons [4]. In fact, most pilots have accepted this as challenges in their working environment. However, a good cockpit design, especially for pilots who have to effectively sit in such a cramped space for prolonged time duration, should remove discomfort and keep their muscles in relaxation mood, instead of developing a habit among pilots to endure the pain and/or ignored it [2]. Though there have been a range of pilot's seat designs developed based on standards and some changes have also been made in the seat's materials, dimensions and hardness to
provide comfort, the complaints still remain. Based on a conducted survey on five different transport aircraft designs, it has been found that there are mismatches between the standards and anthropometric analysis of pilot's seat for modern civil aircraft [3]. With this perception in mind, this paper intends to report on some of the potential mismatches and give some recommendations to alleviate the situation.

2. Methodology
A questionnaire consisting of 90 questions is developed and distributed to respondent pilots, which is aimed to obtain their comments and feedback regarding the ergonomic problems of the cockpit design based on their experiences. Note that for this study, the main focus is placed on the pilot's seat design. The respondents are asked to rate the issue or parameter in question using a numbering scale between 0 and 20, which is adapted from Ref. [5]. The scale reflects their satisfaction on various parameters of the seat, where the participant may select a number between two extreme conditions, for example, either too low (20) or too high (0), while the number ten (10) is considered as the correct design value. Based on their responses to the questions, the answers are collected and averaged. These information may be used to identify as to whether a real problem exists in the cockpit’s design.

Overall, 20 pilots of different nationalities, who are working international flight routes for different airlines, have responded to the survey. 95% of these respondents are males while the remaining 5% are females. More information on the demographic of the respondents on the type of aircraft that they are operating is depicted in Figure 1. This background information is vital to be able to analyze whether the responses are biased towards certain aircraft designs or not.

The summary of results from the survey, in terms of the pilot's seat comfort, is shown in Figure 2. As can be observed, it shows that the current existing pilot’s seats do not offer the opportunity to pilots to establish a comfortable sitting posture. In this case, the anthropometric dimensions might have been selected unsatisfactorily or improperly considered. The results can be used to indicate which part of the seat requires design improvements and the seat design parameters are compared with standards of anthropometric dimensions to find the mismatch with the current seat design.

3. Data Analysis
According to the Webster's Dictionary, comfort is defined as a feeling of relief and enjoyment. Some experts define comfort as a state of being pleasant between human and its environment, and situation. Others simply explain comfort as the absence of discomfort. It is common that pilots on international flights may fly up to about 10 hours continuously. After a few flight hours, pilots usually need to stand and walk to relieve pressure on their back and legs due to the long sitting. The usual and spontaneous pilot’s body movements during sitting in the cockpit is by changing from one buttock to the other, and after a while, pushing himself forward but the shoulder harness holds him back. Hence he starts to feel aching under one of his thighs. In a little while, the pain increases and spreads throughout both thighs. When the pilot or the air crew suffers unbearable pain, they have challenges in their thoughts that may
lead to losing their concentration on flight controls and focus on the body pain [6]. On the other hand, fatigue is caused by sleepiness and tiredness. A main symptom of fatigue is the feeling of exhaustion. The most common types of fatigue between pilots are visual, monotony, chronic, and circadian which extremely lead to reduce pilot’s reaction time and make serious errors [7]. In order to perform safely, the pilots have to be very comfortable in the flight deck. Unfortunately, the pilots have not been taught methods to be comfortable and how to increase it to optimize their limited work station even in seating posture for long hours in the air [7]. It might be hard to assume that a lack of anthropometric design consideration may lead to tragic accident when the flight deck systems have been improperly designed for the specific population.

Anthropometric data represents both static and dynamic dimensions like shoulder breadth and grip strength, respectively. One of well-known anthropometric databases is the US Army Anthropometric Survey (ANSUR) that was collected on 1988 by the US military. In addition, another comprehensive database is the Civilian American and European Surface Anthropometric Resource (CAESAR), which is collected from US and Europe population [8]. CAESAR represents data for both males and females from few different regions: North America, Italy and Netherlands [9]. Another important ergonomics reference in this field is called "Body Space" written by Pheasant, which is also a collected data from both North America and Europe population [10]. Table 1 shows the anthropometric data measurement obtained from different literatures and ergonomics experts for the normal office chair design.

The anthropometric dimension applied for the overall seat design is set corresponding to the 5th of female to 95th of male as the overall population for the minimum and maximum design respectively. It means that it is compatible with 90 percent of users [12]. The seat should accommodate a wide range of population, and values between these percentiles is sufficient for most users. However, this is not meaningful that a woman with 5th percentile of sitting height has thigh length shorter than 5th percentile, therefore the design is performed based on her vision height and she may feel pressure while sitting for long hours on the back of her knees [13].

Table 1: Anthropometric data for office chair design [5, 11]

| Seat Requirements | Anthropometric Measurement | BSR/ HFES100.2002 | BIFMA | DREYFUSS | WOODSON | Grandjean | Diffrient |
|-------------------|---------------------------|-------------------|-------|----------|---------|-----------|-----------|
| Seat height       | Popliteal Height+ Shoe Measure | 38.36            | 38.10-50.50 | 36.80-48.30 | 38.10-45.70 | 38-53     | 35-52     |
| Seat depth        | Buttock Popliteal Length - Clearance Measure | More than 43 | 49.90 | 40.60 | 40.60 | 38-42 | 33-41 |
| Seat width        | Hip Breadth in sitting posture+ Cloth Measure | Less than 45 | More than 45.70 | 40.60-55.90 | 48.30 | 40-45 | 41 |
| Backrest lumbar   | ------ | 12-15 | 15-24.90 | 17.80-29.20 | 17.80-25.40 | NA | NA |
| Seatback width    | more than 31.5 | NA | NA | NA | 32-36 | 33 |
| Backrest height (upper body support) | ------ | Less than 45 | More than 31 | More than 20.30 | More than 20.30 | More than 48.50 | NA |
| Armrest height    | Elbow Rest Height | 18-27 (adjustable) | 17.50-27.40 | 19.10-25.40 | 21.60 | NA | 18-25 |
| Armrest length    | ------ | NA | NA | 25.40-30.50 | 30.50 | NA | 15-21 |
| Distance between armrests | Hip Breadth in sitting posture + Cloth Measure | 46 | 45.70 | More than 48.30 | 48.30 | NA | 48-56 |

*Dimensions are in cm.
3.1. **Seat Height**  
The 5th percentile of female to 95 percentile of male popliteal height should be considered in the seat height dimension. Based on previous literatures, 2.5 cm should be added as shoe heel allowance [11].

3.2. **Seat Depth**  
According to ANSUR anthropometric dimensions, 95th percentile male buttock popliteal length is 54 cm, which is 10 cm greater than the 5th percentile female length. On the other hand, in CEASAR, 95th percentile male buttock popliteal length is 48 cm (12 cm greater than the 5th percentile female length). Therefore, a seat cushion length increase of 10 cm should be considered as the maximum dimension, especially for pilots who are more men than women [13].

3.3. **Seat Width**  
For the dimension of the seat width, the widest hip breadth among the sample population should be measured and applied. In seated position, woman have larger hip breadth than male anthropometric dimensions [13]. The seat width should be comfortable not only for pilot’s seat and cloth allowance but also be comfortable for their arms. It has been recommended 95th percentile of hip breadth with considering 4 to 5 cm for cloth allowance [14]. Another recommendation is to use 95th or 99th of hip breadth female and added 5 cm for heavy clothes [15].

3.4. **Backrest Height**  
For dimension of the upper body support part of the backrest, the sitting shoulder height is considered. The 5th of female to 95th percentile of male is applied [16].

3.5. **Armrest Height**  
The 5th percentile female to 95 percentile male of sitting elbow height data is a determinant for the anthropometric dimension in the armrest height. For the fixed armrest, only 5th percentile of female is considered. However, for this case, the armrest should be adjustable to be more compatible with wide international population. 5th to 95th seated elbow height is applied [17].

3.6. **Armrest Length**  
Armrest are useful for upper limbs support and for keeping body balanced. The best anthropometric measurement for armrest length is the elbow-to-wrist length of 95th percentile of male. It should be supported at least two-thirds of forearm to be more comfortable [17].

3.7. **Width between Armrest**  
Armrests should accommodate 95th percentile female that have the largest hip breadth in order to be comfortable, with enough clearance for clothes [18]. Based on other ergonomists, they believe that armrests clearance should be able to accommodate the 95th percentile elbow breadth male for the minimum separation between armrests [15]. Other experts apply 5th female to 95 male elbow breadth with additional three centimeters to account for heavy clothes [19].

3.8. **Backrest Width**  
The dimension of backrest width should be determined using the shoulder width or bideltoid breadth [20]. Reynolds recommended 95th percentile chest width of male to determine the minimum width in the upper part of the backrest seat while Maertens recommended 95th percentile waist breadth of male to specify the backrest width [13].

3.9. **Headrest Height**  
For the headrest height, dimensions from chin to crown needs to be measured. To accommodate more population, 5th percentile of female to 95th percentile male for minimum and maximum headrest is applied [21].

3.10. **Headrest Width**  
For the headrest width, the maximum breadth across the ears is measured. To accommodate with more population, 5th percentile of female to 95th percentile male for minimum and maximum headrest is applied [21].
All in all, the comparison between AS290B (Aerospace standards and biomechanical requirements) and two anthropometric database standards: ANSUR and CAESAR is summarized in Table 2.

Table 2: Anthropometric data for the flight deck seat design [3, 22, 23]

| Seat Requirements                           | AS290B    | ANSUR     | CAESAR    |
|--------------------------------------------|-----------|-----------|-----------|
| Seat height                                | 33 - 51   | 38 - 51.5 | 33.44 - 44.87 |
| Seat depth                                 | 41 - 45   | 44 - 54.60| 36.66 - 48.09 |
| Seat width                                 | min 43    | 48.22 - 50.32 | 50.10 - 55.66 |
| Backrest height (Upper body Support)       | min 65    | 53.92 - 67.66 | 52.29 - 65.58 |
| Seatback width                             | 20 - 32   | 17.57 - 27.37 | 19.25 - 28.70 |
| Armrest height                             | min 28    | 23.78 - 31.61 | 21.33 - 29.20 |
| Armrest length                             | min 47    | 41.47 - 62.06 | 40.20 - 64.52 |
| Distance between armrests                  | 43 - 46   | 39.70 - 53.48 | 38.47 - 55.03 |
| Headrest height                            | NA        | 21.41 - 23.41 | 22 - 26     |
| Headrest width                             | NA        | 13.66 - 16.08 | 13 - 16.24  |

*Dimensions are in cm

4. Discussion and Conclusion
It can be observed from Table 2 that several mismatches exist between pilot's seat design dimensions standards and the common North American and European anthropometric databases. To remedy this situation, several highlights can be made to be considered for determining new dimensions for current seats as follows:

- The maximum seat height in CAESAR dimensions is less than the dimension in AS290B and the minimum dimension in ANSUR is more than the standards. AS290B and the minimum dimension in ANSUR is more than the standards
- There is a mismatch between maximum dimension of seat depth in AS290B and CAESAR. Maximum dimensions based on ANSUR is 54.60 and 9.60 cm and is different with aerospace standards. In the standards, the maximum seat depth is less than the anthropometric found from both USA and Europe populations
- Backrest height obtained from ANSUR and CAESAR are based on shoulder height, which has a mismatch between the minimum and maximum height in AS290B standard
- Backrest width according to CAESAR and ANSUR data for shoulder width is different with AS290 standard. The minimum in AS290 standard is higher than 5th shoulder width while the maximum dimension is also less than the 95th percentile male in the CAESAR and ANSUR.

In conclusion, this study has established the notion that the design guidelines used for pilot's seat may not be adequate to cater for varied anthropometric characteristics of today's pilots. The mismatch should be taken into account to improve the design quality of pilot's seat in the future.

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