The Comfort Design for Civil Aircraft Cabin Using Ergonomics Theory

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Abstract. In order to improve the comfort of civil aircraft cabin, the cabin comfort system is built in this research based on the ergonomics theory and considering the influence of cabin environment, facilities, configuration, etc. In this process, filtrating and classification for the indexes which mainly influence the comfort are conducted, weight value setting is completed according to the analytic hierarchy process method and the quantify score for all the indexes is pushed. Finally, the results of cabin comfort evaluation are obtained. The case analysis results verify the effectiveness of the method. To sum up, based on this method proposal in this research, the main factors that can influence the comfort of the cabin are obtained, the comfort factors of the cabin are quantized and analysed, and last, these research results could direct the cabin comfort design.

Keyword: civil aircraft cabin; comfort design; ergonomics theory; evaluation system; analytic hierarchy process

1. Introduction
Nowadays passenger’s comfort has become one of the important factors in the cabin design of civil aircraft, since the passenger’s requirement for aircraft comfort has been continuously increased with the development of economy and the improvement of people's living [1-3]. Civil aircraft cabin comfort mainly involves cabin cross-section design, cabin layout, interior, lighting effects, cabin noise and vibration, as well as systems and equipment such as seats, trunks and passenger service devices. Systematic cabin evaluation can provide guidance for the design process of civil aircraft cabin as well as data support and design feedback for designers, which is of great significance. However, work in this area still needs to be improved.

At present, the evaluation methods of civil aircraft cabin comfort mainly include subjective evaluation and objective evaluation. Subjective evaluation method refers to the use of various subjective scales, questionnaires or interviews to derive the subjective comfort evaluation of the subjects. Subjective evaluation method needs to set the weight values of each indicator, which has greater subjectivity and varies with each individual, consequently reducing the credibility of the evaluation results [4, 5]. The objective evaluation method is mainly to measure and statistically analyse the physiological data of the subjects, such as pressure distribution, myoelectric signals, EEG signals, etc., which can reflect the comfort or discomfort of the subjects. The objective method establishes an evaluation model through quantifiable indicators. However, the model needs a great number of sample points and there are usually big differences between sample points. It needs to verify the accuracy of the model [6, 7].

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In this paper we present an evaluation system which can quantitatively assess the comfort of civil air-craft cabins. Firstly, the designers build a comfort index system based on different factors associating with the cabin comfort design. Secondly, through the analytic hierarchy process and considering the incommensurability between the indicators, the weight values of each indicator are set. Finally, we applied this method to the comfort evaluation and compilation of three different designs of dual-channel civil aircraft cabins, which verifies the feasibility and effectiveness of our evaluation system.

2. Cabin comfort assessment system

Cabin comfort design involves multidisciplinary knowledge such as cabin environment, cabin configuration, cabin facilities, cabin interior, cabin facilities, cabin entertainment system, seat comfort and service, so the assessment of cabin comfort design is a comprehensive Multi-factor evaluation system. Based on the establishment of a comprehensive multi-factor evaluation system, expert questionnaire survey and scientific data analysis are carried out on the system, and then the effects of various factors on cabin comfort design can be quantified. Finally, through engineering discussion, the cabin design scheme with better comfort can be determined. According to the design process of the civil aircraft cabin, the equipment and systems involved and the criteria such as ergonomics and etc., the main civil aircraft cabin design elements are selected, and the cabin comfort evaluation system can be summarized as shown in Figure 1.

![Evaluation System for Cabin Comfort Design](image)

**Figure. 1** The evaluation system for cabin comfort design.

In view of the above-mentioned cabin comfort evaluation system, the statistical data of cabin comfort system rating are obtained by means of design expert investigation. These data are the basis of cabin comfort design for civil aircraft. Based on the effective statistical data, the data are analysed by the combined evaluation method adopted in this paper, and the engineering discussion of cabin comfort is carried out. Finally, a multi-objective balanced optimal cabin design scheme can be determined.

3. Combined evaluation method

In Figure 1, there are six criteria and 20 indicators for cabin comfort. Therefore, it is a typical multi-attribute decision-making problem. Among them, the rationality of the weight setting of each comfort index will directly affect the evaluation conclusion of cabin comfort. In this paper, a combination evaluation method is used to analyse data samples [8]. In the weight setting of each indicator system, the analytic hierarchy process is used to compare the importance of each level of the comfort indicator system described in Figure 1 through the expert survey score, and finally derive the
weight values of the bottom level indicator layer to the top level target layer. Subjective indicators, such as "access convenience" and "personal privacy space", are transformed into quantitative indicators. Then quantitative indicators are further analysed. For example, quantifiable indicators are divided into six types: cost type, benefit type, fixed type, interval type, deviation type and deviation interval type. Finally, the existing evaluation in document [8] is adopted. The model carries on the numerical analysis to each index.

The cabin comfort index $P(x)$ is composed of subjective evaluation $\varphi(x)$ and objective evaluation $\psi(x)$. The expressions are as follows:

$$P(x) = \alpha \sum_{i=1}^{N_1} \varphi(x_i) + \beta \sum_{j=1}^{N_2} \psi(x_j)$$ (1)

In the formula, $N_1$ is the number of subjective comfort indicators and $N_2$ is the number of objective comfort indicators. $\alpha$ and $\beta$ are the weights of subjective and objective evaluation results, which are determined by analytic hierarchy process. $\alpha \in [0,1], \beta \in [0,1], \alpha + \beta = 1$.

Generally, when evaluating ergonomics, it is necessary to consider the predicted value of human factor failure probability (mainly considering the effect of human factors on the accuracy of operation, which should be taken into account in the evaluation of human factor or maintainability of cockpit). In the case of cockpit comfort, the predicted value of human factor failure probability should be considered. However, in the case of cabin comfort, passengers have less interaction with cabin equipment during flight. In this paper, the predicted value of human failure probability is not considered.

### 3.1 Weight Setting of Comfort Index

The weight of the comfort index is set by the analytic hierarchy process. Firstly, the indicator layer in the comfort index system is weighted, and then the indicators under each criterion are weighted. The weight settings follow the following process:

Firstly, the judgment matrix is constructed, which divides the comparison results of the two indicators into scales of equally important, slightly important, obviously important, strongly important and extremely important. The cabin design experts only need to give the upper half matrix scale or the lower half matrix scale of the matrix diagonal, and the other half matrix can directly take its reciprocal. In order to quantify the evaluation indexes, the relative weights of the indexes can be measured according to the (1-9) scaling method in document [8]. According to the scaling meaning, the equally, slightly, obviously, strongly and extremely important values of the experts' evaluation can be assigned to 1, 3, 5, 7 and 9 respectively. Each subjective judgment made by the experts can be assigned to a value knot to get a sum and mean value.

Secondly, a consistency check on cabin comfort factors is required. The consistency check is performed on the judgment matrix by using $C.R. = C.I./R.I.$ Among them, $C.R.$ is the consistency ratio of the judgment matrix, $C.I.$ is the consistency index of the judgment matrix and $R.I.$ is the average random consistency index of the judgment matrix. When judging the consistency ratio of the matrix $C.R. = C.I./R.I. < 0.1$, the judgment matrix has satisfactory consistency. Otherwise, it is necessary to use the expert experience to modify the judgment matrix again until the consistency test is passed. The average random consistency index RI values are shown in Table 1.

| order | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|-------|---|---|---|---|---|---|---|---|---|
| RI    | 0 | 0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

### 3.1.1 Weight Setting of Criteria Layer

Evaluation of experts at all levels, $CI = 0.0318$, indicating that the expert evaluation meets the consistency requirements. The criterion layer construction matrix and the weight values of each criterion are shown in Table 2.
**Table 2.** The matrix and the weight value of criterion level

|                      | Cabin environment U1 | Cabin configuration U2 | Cabin facility U3 | Seat comfort U4 | In-flight entertainment U5 | Weights |
|----------------------|----------------------|------------------------|-------------------|-----------------|----------------------------|---------|
| Cabin environment U1 | 1.000                | 1.000                  | 3.000             | 0.500           | 3.000                      | 0.2276  |
| Cabin configuration U2 | 1.000               | 1.000                  | 3.000             | 1.000           | 5.000                      | 0.2815  |
| Cabin facility U3    | 0.333                | 0.333                  | 1.000             | 0.333           | 3.000                      | 0.1085  |
| Seat comfort U4      | 2.000                | 1.000                  | 3.000             | 1.000           | 5.000                      | 0.3259  |
| In-flight entertainment U5 | 0.333       | 0.200                  | 0.333             | 0.200           | 1.000                      | 0.0566  |

3.1.2 Weight Setting of Index Layer. Similar processes at the criteria level are used to set the weight of each index. The results are shown in table 3.

**Table 3.** The weight value of comfort index

|                  | Cabin environment | Cabin configuration | Cabin facility | Seat comfort | In-flight entertainment | Weights |
|------------------|-------------------|---------------------|----------------|--------------|-------------------------|---------|
| temperature      | 0.3270            | 0.0744              |                |              |                         |         |
| humidity         | 0.1009            | 0.0230              |                |              |                         |         |
| noise            | 0.4534            | 0.1032              |                |              |                         |         |
| light            | 0.0468            | 0.0107              |                |              |                         |         |
| Interior         | 0.0719            | 0.0164              |                |              |                         |         |
| Seat pitch       |                   | 0.4067              |                |              |                         | 0.1145  |
| Luggage rack height | 0.2963         | 0.0834              |                |              |                         |         |
| Aisle width      | 0.1451            | 0.0408              |                |              |                         |         |
| Aisle height     | 0.0592            | 0.0167              |                |              |                         |         |
| Number and location of lavatory | 0.0927 | 0.0261              |                |              |                         |         |
| Luggage rack space |                 | 0.4875              |                |              |                         | 0.0529  |
| Passenger service unit | 0.2234         | 0.0242              |                |              |                         |         |
| Porthole design  | 0.1266            | 0.0137              |                |              |                         |         |
| lavatory         | 0.1625            | 0.0176              |                |              |                         |         |
| Seat size        |                   | 0.6893              |                |              |                         | 0.2246  |
| seat back adjustability |           | 0.1264              |                |              |                         | 0.0412  |
| Lumbar support   | 0.1264            | 0.0412              |                |              |                         |         |
| Seat material hardness | 0.0579        | 0.0189              |                |              |                         |         |
| Cabin entertainment |                 | 0.8333              |                |              |                         | 0.0472  |
| In-flight communication |         | 0.1667              |                |              |                         | 0.0094  |

3.2 Evaluation Model of Subjective Indicators

In this paper, Miller's method is used to set the subjective evaluation level of comfort to 5 levels, namely 0, 2.5, 5, 7.5 and 10. 0 means very bad, inappropriate, etc. 2.5 means slightly better, but not
suitable for acceptance. 5 means general and acceptable. 7.5 means good. 10 means excellent. Specific quantitative criteria for subjective indicators is shown in tables 4 and 5.

### Table 4. The quantification standard of subjective comfort index

| Comfort criterion | Comfort Index   | evaluation result |
|-------------------|----------------|-------------------|
| Cabin environment | Cabin color matching | 0, 2.5, 5, 7.5, 10 |
| ...              | ...            |      √            |
| Seat comfort      | Seat material hardness | 0, 2.5, 5, 7.5, 10 |

### Table 5. The index list of subjective comfort

| Comfort criterion | Comfort Index   | Subjective indicator | Objective indicator | Index type | Quantization function |
|-------------------|----------------|----------------------|---------------------|------------|-----------------------|
| Cabin environment | light          |                      |                     |            |                       |
|                   | Interior       |                      |                     |            |                       |
| Cabin facility    | Passenger service unit |                |                     |            |                       |
|                   | Porthole design |                      |                     |            |                       |
|                   | Lavatory and gallery design |        |                     |            |                       |
| Seat comfort      | Lumbar support |                      |                     |            |                       |
|                   | Seat material hardness |                |                     |            |                       |
| In-flight         | Cabin entertainment |                |                     |            |                       |
| entertainment     | In-flight communication |             |                     |            |                       |

### 3.3 Evaluation Model of Objective Indicators

The list of objective comfort indicators is shown in Table 6. Among them, the benefit attribute refers to the attribute whose value is the bigger the better, the cost attribute refers to the attribute whose value is the smaller the better, the fixed attribute refers to the attribute which is better when its value is closer to a fixed value, and the interval attribute refers to the attribute which is better when its value is to a fixed interval (including falling into the interval). However, the deviation attribute refers to the attribute whose value is better when deviating further from a fixed value and the deviation interval attribute refers to attribute whose value is better when deviating further from a certain interval.

### Table 6. The index list of objective comfort

| Comfort criterion       | Comfort Index   | Index type | Quantization function |
|-------------------------|----------------|------------|-----------------------|
| Cabin environment       | temperature    | Interval   | $f_{\text{region}}$  |
|                         | humidity       | Interval   | $f_{\text{region}}$  |
|                         | noise          | Cost       | $f_{\text{cost}}$    |
| Cabin configuration     | Seat pitch     | benefit    | $f_{\text{benefit}}$ |
|                         | Luggage rack height |          | $f_{\text{region}}$ |
|                         | Aisle width    | benefit    | $f_{\text{benefit}}$ |
|                         | Aisle height   | benefit    | $f_{\text{benefit}}$ |
|                         | Number and location of lavatory | | $f_{\text{benefit}}$ |
| Cabin facility          | Luggage rack space |    | $f_{\text{benefit}}$ |
| Seat comfort            | Seat size      | benefit    | $f_{\text{benefit}}$ |
|                         | seat back adjustability | | $f_{\text{benefit}}$ |
\[ f_{\text{region}} = \begin{cases} \frac{5(x_j - c)}{c - q} + 10, & x_j < c \\ 10, & x_j \in (c, d) \\ \frac{5(x_j - d)}{d - q} + 10, & x_j > c \end{cases} \]  \tag{2}

\[ f_{\text{cost}} = \frac{5(x_j - p)}{q - p} \]  \tag{3}

\[ f_{\text{benefit}} = \frac{5(x_j - q)}{p - q} \]  \tag{4}

In the above formula, P and Q are the upper and lower limits of values respectively, and \([c, d]\) is the interval value of interval attributes. In order to ensure consistency with the subjective quantization value range, 5 is used as the boundary point of quantization value. The optimal value is 10, and the worst value is 0.

4. Examples and results analysis

In this study, three typical double-channel passenger cabins are selected for comparison. Aircraft A and B have been delivered to operation, while Aircraft C is in the design stage. The analysis results are shown in Table 7.

| Comfort Index                        | weight | Aircraft A | Aircraft B | Aircraft C |
|--------------------------------------|--------|------------|------------|------------|
| temperature                          | 0.0744 | 8.4        | 8.4        | 8.4        |
| humidity                             | 0.0230 | 9.3        | 9.3        | 9.3        |
| noise                                | 0.1032 | 7.9        | 7.9        | 7.9        |
| light                                | 0.0107 | 9.0        | 10.0       | 9.0        |
| Interior                             | 0.0164 | 9.0        | 10.0       | 9.0        |
| Sear pitch                           | 0.1145 | 8.5        | 8.5        | 8.5        |
| Luggage rack height                  | 0.0834 | 7.7        | 8.3        | 8.3        |
| Aisle width                          | 0.0408 | 8.5        | 9.3        | 9.3        |
| Aisle height                         | 0.0167 | 7.4        | 8.6        | 8.6        |
| Number and location of lavatory      | 0.0261 | 8.5        | 8.7        | 9.0        |
| Luggage rack space                   | 0.0529 | 8.3        | 8.3        | 8.3        |
| Passenger service unit               | 0.0242 | 9.0        | 9.0        | 9.0        |
| Porthole design                      | 0.0137 | 9.1        | 8.3        | 8.5        |
| lavatory                             | 0.0176 | 9.0        | 10.0       | 9.0        |
| Seat size                            | 0.2246 | 7.4        | 8.5        | 8.5        |
| seat back adjustability              | 0.0412 | 8.1        | 8.1        | 8.1        |
| Lumbar support                       | 0.0412 | 7.5        | 8.7        | 8.7        |
| Seat material hardness               | 0.0189 | 9.1        | 9.5        | 9.3        |
| Cabin entertainment                  | 0.0472 | 8.5        | 8.7        | 8.7        |
| In-flight communication              | 0.0094 | 7.7        | 8.2        | 8.2        |
| Comfort quantitative score           | 8.1    | 8.6        | 8.3        | 8.5        |

5. Concluding remarks

From the perspective of ergonomics, this paper establishes an evaluation model of cabin comfort. Through the analysis of factors affecting the comfort, the various evaluation indicators are classified
and stratified, and a more reasonable evaluation system of cabin comfort is established. By using the analytic hierarchy process, it's found that the most influential indicators of cabin comfort are seat size, seat pitch, noise, height of luggage rack, temperature and space of luggage rack. It should be pointed out that the reasonableness of setting the weights of comfort indicators depends on the qualification of experts and the reliability of scoring. The method in this paper does not involve factors in this respect. Therefore, based on the improved hierarchy method, the number of scoring experts can be further increased and the accuracy of the method can be improved to guide the design of airplane cabin comfort.

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