Climatic Environmental Worthiness Model of the Civil Aircraft Based on the Grey Theory

Zhang Hui¹ and Wu Jingtao¹
¹Aircraft Strength Research Institute, Xi’an, Shan Xi, China
Email: zhanghui07282006@163.com

Abstract. The civil aircraft must have the ability to the global operation. The aircraft may experience the high temperature, the low temperature, the high humidity, ice and other extreme climatic environment. Environmental worthiness plays an important role in the integrated capability of the civil aircraft. Environmental worthiness evaluation is a major part of the civil aircraft engineering. According to the environmental worthiness to diversified environmental factors, we can establish the criteria for environment classification. The environmental worthiness model of the civil aircraft was set up using the grey theory. The rationality and feasibility of the model was validated by the example. The results indicate that the environmental adaptability of the aircraft was ranked “poor” to “better”. The result can supply the reference data for the environment adaptability requirement for the design of the civil aircraft.

1. Introduction
The aircraft during the service may experience the extreme climatic environment. The ability of the aircraft adapting to the environment profile during the life cycle can be defined as the environmental worthiness. The environmental worthiness is one of the general features of the aircraft. According to the NSTB database tracing aviation accident, the flight accidents due to the extreme weather account for 20.1%. The US military clearly pointed out the extreme climatic may bring out the equipment in the aircraft losing efficacy. The extreme climatic will influence the function and the performance of the aircraft. Therefore, how to appropriately evaluate the environmental worthiness has become a pivotal case.

Analysis Hierarchy method(AHP)[1-3] was proposed by professor T.L. Safety in 1970s, which is a decision method with both quantitative and qualitative analysis. AHP was used for estimating weights of each criterion. The worthiness model is constructed by the grey theory with the AHP. A sophisticated method is created for the evaluation of the environmental worthiness [4-6].

2. The failure of the aircraft in the extreme weather
The extreme climatic will influence the function and the performance of the aircraft. The high temperature, the low temperature, humidity, the freezing, the sleet and the solar radiation can be achieved in the facility, which we can use to evaluate the worthiness of the aircraft to the defined climatic environment.

The high temperature and the solar radiation may deteriorate the properties of the materials, even cause the equipment, the components and the parts failure. The high temperature also causes the fuel losing the lubrication characteristics which may bring the vapor lock. The properties of the electronic
equipment may decrease because of the high temperature.

The low temperature may increase the viscosity of the grease and it even may be frozen. The APU, 
engineer and the electronic equipment can’t start in the low temperature.

The humidity may condense nearby the electronical box, which may bring the electronic short 
circuit.

The flaps and flats may be hard to control in freezing weather.

The sleet drops may permeate through the equipment box and cause the short circuit.

3. Building evaluation model
There are so many climatic factors at different levels to impact the climatic environment worthiness.
The classification has fuzziness and the different abilities. It is difficult to evaluate the credit of the 
c Climatic worthiness [7-9].

A mathematical model of a fuzzy grey [10] comprehensive evaluation can be expressed as follows:

3.1. Establish the evaluation Factors
To evaluate the credit of the environment worthiness, one must first establish a criteria system. This 
enables an understanding of the relationships between influencing factors so the system can make the 
desired evaluation.

The scheme of the evaluation is denoted by \( U_n = \{U_1, U_2, U_3 \ldots \} \), the second layer is the test 
climatic factors, which is denoted by:

\[
U_1 = \{u_{11}, u_{12}, u_{13}, u_{14}, \ldots, u_{1m}\} \\
U_2 = \{u_{21}, u_{22}, u_{23}, u_{24}, \ldots, u_{2m}\} \\
U_n = \{u_{n1}, u_{n2}, u_{n3}, u_{n4}, \ldots, u_{nm}\}
\]

Determining the comparative judgment matrix:

\( U = \{u_{ij}\}_{n \times m} \) (4)

In formula(4), \( n \) is the number of the evaluation number, \( m \) is the number of the climatic influence 
 factors, \( u_{ij} \) represents the quantized value of the scheme \( i \) to the factors \( j \).

3.2. Normalize the index values
Normally, the dimension and the range of the evaluation data in the formula (4)are different. Therefore, 
the datas should be normalized. The normalization equation is defined as follows

\[
f_{ij} = \frac{a_{ij} - \min_{1 \leq i \leq n}(a_{ij})}{\max_{1 \leq i \leq n}(a_{ij}) - \min_{1 \leq i \leq n}(a_{ij})}
\]

Thereinto, \( i=1,2,\ldots,n, j=1,2,\ldots,m \)

We get the evaluation normalizationmatrix:

\[
F= \begin{bmatrix}
F_1 \\
F_2 \\
\vdots \\
F_n
\end{bmatrix} = \begin{bmatrix}
f_{11} & f_{12} & \ldots & f_{1n} \\
f_{21} & f_{22} & \ldots & f_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
f_{n1} & f_{n2} & \ldots & f_{nn}
\end{bmatrix} = [f_{ij}]_{n \times m}
\]

3.3. Calculating the weight of each indicator according to the judgment matrix
The weight vector can be confirmed by the method of all evaluative experts on the evaluation indexes 
or by the entropy method. Considering the indices have little relevance or even no correlation. We use 
the entropy method.
The information entropy of the index can be obtained using this formula:

$$ e_j = \begin{cases} -\sum_{i=1}^{n} p_{ij} \ln(p_{ij}), & p_{ij} > 0 \\ 0, & p_{ij} = 0 \end{cases} \quad i = 1, \ldots, n; \ j = 1, \ldots, m ; $$

(8)

In which, $k$ is a coefficient, $k = \frac{1}{\ln(n)}$.

The redundancy of the information entropy is calculated by:

$$ d_j = 1 - e_j $$

(9)

The weights of each indicator are calculated as follows:

$$ \omega_j = \frac{d_j}{\sum_{j=1}^{m} d_j} $$

(10)

3.4. Calculate the related degree coefficient

For the evaluation index, the higher the value, the better the ability of the adaptability to the extreme climatic environment. According to the gray system theory, the optimum reference array is $f_0 = [f_{01}, f_{02}, \ldots, f_{0m}]$.

In formula (5), $f_0 = \max \{f_{ij} | i = 1, 2, \ldots, n\}$.

The comparison array is $f_i = [x_{i1}, x_{i2}, \ldots, x_{im}]$, then we can get the improved grey related coefficient degree as follows:

$$ \xi_{ij} = \frac{\min \{\min (|f_{ij} - f_{0j}|) + \rho \max \{\max (|f_{ij} - f_{0j}|)\} \}}{\sum_{i=1}^{n} |f_{ij} - f_{0j}|} $$

(11)

Where $\rho$ is distinguishing parameter, $0 \leq \rho \leq 1$, it is usually set as 0.5.

Then we can get related degree matrix $E$:

$$ E = (\xi_{ij})_{n \times m} $$

(12)

3.5. Calculate the comprehensive evaluation matrix

Using the grey relation analysis, the comprehensive evaluation result matrix is as follows:

$$ R = \omega \times E^T $$

(13)

4. Example and Analysis

The aircraft during the test will be assessed after experiencing the extreme climatic. Considering the actual operation environment, the extreme climatic include the high temperature, the low temperature, humidity, the freezing, the sleet, the solar radiation. According to the checking result after the test, the original scores can be seen in following table 1-table3, which is the environmental worthiness value to the single environment for different sorties. Each column of the matrix is the aircraft’s evaluation value which is given by eight experts. The comprehensive result can be obtained by the the averaging method.

**Table 1.** Original data of the A1 aircraft

|        | high temperature | low temperature | solar radiation | humidity | sleet | freezing |
|--------|-----------------|----------------|-----------------|---------|-------|----------|
| 1      | 0.652           | 0.518          | 0.623           | 0.600   | 0.718 | 0.415    |
| 2      | 0.452           | 0.534          | 0.632           | 0.888   | 0.718 | 0.400    |
| 3      | 0.434           | 0.623          | 0.888           | 0.899   | 0.698 | 0.467    |
| 4      | 0.678           | 0.455          | 0.544           | 0.721   | 0.723 | 0.487    |
The judgment matrix of paired-comparisons can be established, which can be seen in table 4:

**Table 4. The judgment matrix**

| Number          | high temperature | low temperature | solar radiation | humidity | sleet | freezing |
|-----------------|------------------|-----------------|-----------------|----------|-------|----------|
| A1 Aircraft     | 0.612            | 0.653           | 0.676           | 0.751    | 0.725 | 0.468    |
| A2 Aircraft     | 0.716            | 0.583           | 0.439           | 0.733    | 0.830 | 0.500    |
| A3 Aircraft     | 0.584            | 0.734           | 0.646           | 0.735    | 0.758 | 0.352    |

According to the formula (5), we can get the normalization matrix:

\[
X = \begin{bmatrix}
0.2121 & 0.4636 & 1 & 1 & 0 & 0.7838 \\
1 & 0 & 0 & 0 & 1 & 1 \\
0 & 1 & 0.873 & 0.1111 & 0.3143 & 0
\end{bmatrix}
\]

(14)

The evaluation weight matrix of grey type for respective indexes based on step 3 are as follows:
\[ \omega = [0.1952, 0.1458, 0.1254, 0.2379, 0.1687, 0.1270] \]  
(15)

Computing the related degree Coefficient:
\[ \gamma = \begin{bmatrix} 0.3882 & 0.4824 & 1 & 1.000 & 0.3333 & 0.6981 \\ 1 & 0.3333 & 0.333 & 0.3333 & 1.000 & 1 \\ 0.3333 & 1 & 0.7980 & 0.3600 & 0.4217 & 0.333 \end{bmatrix} \]
(16)

The information of the entropy based on step are as follows:
\[ R = [0.6543, 0.6606, 0.5101] \]
(17)

From the results, it can be concluded that the environmental adaptability of the second sortie aircraft (A2) is the best, the first sortie aircraft (A1) is the second, and that of the third sortie aircraft (A3) is the worst.

5. Conclusions
The study is mainly focused on the comprehensive evaluation of the worthiness to the extreme climatic which can be achieved in the climatic environment test facility. The paper constructs evaluation model by combining grey evaluation method with AHP. The model provides a new comprehensive method to evaluate worthiness ability of the aircraft. It plays an important role in optimizing Aircraft Design and improving aircraft’s worthiness ability.

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References
[1] Xuanzi, Hu .Application of grey clustering theory combined with AHP in railway station evaluation, Proceedings of IEEE ICIA 2006, pp 1289-1294, 2006.
[2] WANG Wenke and Liu Peide. The evaluation of urban public traffic line network based on the Grey-AHP method, International Conference on Transportation Engineering 2007, pp.1991-1996, 2007.
[3] Minghui, Zhang.A Comprehensive College Coaches Evaluation Model Based on AHP and Grey Correlation Theory, Proceedings 2015, pp.330-334, 2015.
[4] Guozhong Huang and Siheng SunSafety. Evaluation of Construction Based on the Improved AHP-Grey Model, Wireless Personal Communications, vol 103, pp 209–219, 2018.
[5] Shulin Li. Evaluation model of environmental worthiness for military aircraft, Aeronautic Sinica, vol 4, pp.1055-1057, 2009.
[6] Zong-Feng Q.I., GuoSheng Wang. Effectiveness evaluation of electronic warfare command and control system based on grey AHP method, Journal of Chemical and Pharmaceutical Research, vol 6, pp. 535-542, 2014.
[7] Fei, Lv.Aircraft financial leasing project risk evaluation using AHP and grey comprehensive algorithm, International Journal of Digital Content Technology and its Applications, vol 6, pp 259-267, 2012.
[8] Xia, Chunyan.Method of weight assignment for multi-criterion based on grey interval AHP, Advanced Materials Research, vol 243-249, pp 5285-5288, 2011.
[9] Sun, Yang. Research on an intelligent behavior evaluation system for unmanned ground vehicles, Energies, vol 11, pp 1-22, 2018.
[10] Xiaoxi, Guo.A grey relational analysis model of scientific research ability on music based on AHP and its realization, Journal of Signal Processing, Image Processing and Pattern Recognition, vol 8, pp. 211-222, 2015.