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RESEARCH ON THE ENVIRONMENTAL WORTHINESS OF THE CIVIL AIRCRAFT USING THE FUZZY THEORY

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Abstract

In the flight envelope of the civil aircraft，it will encounter the extreme climate conditions inevitably such as high temperature, cold and ice. The verification time of the climate environmental worthiness can be shortened by the aircraft climate environment test. The influence of the extreme climate to the civil aircraft is analyzed. Construct the environmental worthiness model using the fuzzy comprehensive evaluation theory with the analytic hierarchy process (AHP), the environmental worthiness of the aircraft can be obtained through this method with the test result. Quantitative evaluation of the aircraft climate environment worthiness can provide data reference for the aircraft design improvement and the flight envelope expansion.

Keywords: climate environmental worthiness; fuzzy comprehensive evaluation; analytical hierarchy process; flight envelope

1. Environmental worthiness

In the standard MIL-STD-810G《Environmental Engineering Considerations and laboratory tests》, environmental worthiness is defined as "The equipment is expected to perform all its functions, properties and not to be destroyed under the prospective environments during its life cycle, which is one of the important quality characteristics of the equipment" [1]. For the civil aircraft, the environmental worthiness can be tested and evaluated through the test result and the theoretical method.

The extreme climatic conditions such as high temperature, cold and ice may cause the cabin door stuck because of the deformation, landing gear to become stuck or out of step, movable wing surfaces to freeze and the other problems. During the development and airworthiness certification phases, airworthiness regulations require the civil aircraft to have the analytical and experimental methods to demonstrate the conformity of the functions and performance of the typical structures or mechanisms, such as hatch doors, landing gears and movable wing surfaces under the extreme climatic conditions.

The high temperature may cause the gas plug of the fuel system, the performance of the electrical equipment and the bearing capacity of the structural materials.

Cold may cause the auxiliary power unit, engines and electronic equipment to fail to start properly, fluid or fuel to freeze, and movable wing surfaces to become stuck.

Icing not only deteriorates the aerodynamic and stability characteristics of the civil aircraft during take-off, but also may block the discharge holes of the aircraft, which may lead to the failure of the discharge system. During the ice weather, the tire of the landing gear ground may be damaged.

2. Climatic Environmental Test

The climatic environmental test can expose the design defects of the aircraft climatic environmental adaptability. When we conduct the test in the laboratory, the experiment period can be shortened and the repeatability is high.

For materials, structures, systems and parts of the whole aircraft, carry out natural environmental test and laboratory environmental test to evaluate the climate environmental worthiness. With the emphasis on the quality construction of the civil aircraft in China, there is an urgent need to improve the climate environment adaptability of civil aircraft. The various environmental measures to verify and examine the climate environment adaptability are taken in the development process. The evaluation of climate environmental adaptability has graduall y become an important part of the environmental work.

3. Climatic Environmental Worthiness Evaluation

3.1 The theory of the fuzzy comprehensive evaluation

In the operation phase, the civil aircraft may encounter extreme climatic conditions inevitably such as high temperature, cold and ice. Despite the probability of occurrence of these extreme weather conditions is very low in the natural region, with the globalization of the civil aviation, the civil aircraft are widely used and they may experience extreme weather in the multi-mission profiles. It is likely to encounter surface weather conditions around the world. Extreme weather conditions may affect the normal use of the aircraft, and in order to improve the economy and safety of the civil aircraft and make them better adapt to the complex and changeable climatic conditions, it is necessary to construct the evaluation model of the civil aircraft and carry out the climatic environment adaptability evaluation.

Three limitations must be met in the use of environmental evaluation to quantitatively describe the environmental worthiness of a product:

1) The environmental stress can be described by a single quantitative parameter;

2) Within a certain range, the relationship between product failure rate and environmental stress;

3) The fault caused by enough stress is a threshold fault, which has nothing to do with the action time.

Fuzzy comprehensive evaluation has been applied in the field of evaluation due to its advantages of both qualitative analysis and quantitative analysis. Use this method to evaluate the climatic environmental worthiness of the civil aircraft with the result which we get after the laboratory climate experiment. According to the characteristics of the climate parameter and the environmental factors of the civil aircraft, the worthiness model is established using the theory and the membership function of each factor, and the index weighting method is used to evaluate the climatic environmental adaptability of civil aircraft.

The extreme climatic environmental conditions of civil aircraft are determined by airworthiness requirements and the aircraft design envelope. The specific environmental conditions of extreme temperature and extreme icing are the research contents of this project.

3.2 The weight sets of the fuzzy comprehensive evaluation

In the comprehensive evaluation, the weight sets are crucial. It reflects the position that each factor has dominant or the role that each factors has played during the comprehensive evaluation and directly influences the result of comprehensive evaluation. In general, each index in one level has different importance.

In the fuzzy comprehensive evaluation, the weight distribution will influence the evaluation results, it should try to conform to the actual situation. In order to make the decision-making quantitative, the judgment matrix is used to represent the hierarchical model. The relative weight is obtained from the comparison of two relative elements in this level, which can be assigned to the importance degree according to the 1 ~ 9 scale method, and the judgment matrix scale can be obtained.

Table1 The scale of judgment matrix and its meaning

Scale	Implications
1	The two elements are equal importance
3	When the two elements are compared, the former is slightly more important than the latter
5	When the two elements are compared, the former is obviously more important than the latter
7	The former is stronger and more important than the latter
9	When the two elements are compared, the former is more important than the latter
2,4,6,8	Represents the intermediate value of the above adjacency judgment
reciprocal	If the importance ratio of element I to element J is a_{ij}, then the importance ratio of element J to Element I is $a_{ji} = 1/a_{ij}$.

If there are k factors in the evaluation, then the judgment matrix A can be expressed as:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1k} \\ \vdots & \ddots & \vdots \\ a_{k1} & \cdots & a_{kk} \end{bmatrix} \quad (1)$$

In the formula (1), A is the judgment matrix, and $a_{ij}$is the importance ratio of the element I to the element J. After the judgment matrix is determined, the weight set of the factor is obtained by solving the eigenvector corresponding to the maximum eigenvalue of the judgment Matrix. Thus, the requirement solves the eigen equation:

$$AW=\lambda_{max}W \quad (2)$$

In the formula(2), λ_{max} is the maximum eigenvalue of the judgment matrix A. W is the corresponding eigenvectors to the maximum eigenvalue of the judgment matrix. ω_i is the weight value.

3.3 Application Cases

The high temperature, cold and icing tests have been completed in the laboratory. In the climate environmental tests of civil aircraft, the relational function that describes the environmental adaptability of a single environmental factor, namely the temperature relative humidity and the icing parameter needs to be determined first.

First of all, to determine the scope of the environment temperature for the use of civil aircraft, it is denoted as$[T_{min}, T_{max}]$. That is to say, the maximum temperature that civil aircraft can adapt to is T_{max} and the minimum temperature is T_{min}, which belongs to the bilateral constraint index. The most ideal working temperature for the civil aircraft is the median value, when the temperature is very high or very low, it will affect the function and performance of the civil aircraft, so we choose the normal distribution membership function, the mean value is the median value of the constraint condition, the variance is 1/6 of the constraint condition difference, the membership function of the ambient temperature is:

$$A_1(\mathrm{x}) = \mathrm{e}^{-\left(\frac{x-a}{\sigma}\right)^2} \quad (3)$$

In this formula (3), $a = \frac{T_{min}+T_{max}}{2}$, $\sigma = \frac{T_{max}-T_{min}}{6}$.

According to the climate test conditions of the civil aircraft, the recommended high working temperature is 70 ° C (or the related technical documents) and the low working temperature is -55 ° c (or the related technical documents). In this study, the membership function of the temperature is:

$$A_1(\mathrm{x}) = \mathrm{e}^{-\left(\frac{x-7.5}{20.8}\right)^2} \quad (4)$$

In the flight envelope of the civil aircraft, the relative humidity belongs to the unilateral restraint index and the maximum relative humidity is H_{max}. Therefore, according to the actual situation, the boundary default parameter or the expected value can be determined first, then the membership function can be determined. Generally, we can choose the lower boundary H_{min}= 0, but when H_{min}= 0, the air is dry, which will also affect the performance of the civil aircraft. At this time, we also need to estimate the expected value. Since the relative humidity varies from 0% to 100%, follow the approach to decide the bilaterally constrained indicators, we select $a = 50\%, \sigma = \frac{H_{max}}{6}$ .The membership function of the humidity is:

$$A_2(\mathrm{x}) = \mathrm{e}^{-\left(\frac{6(\mathrm{x}-0.5)}{H_{max}}\right)^2} \quad (5)$$

For relative humidity, the recommended relative humidity in the laboratory climate test conditions for the aircraft is $\mathrm{H} = 100\%$. In this study, the membership function of the humidity is:

$$A_2(\mathrm{x}) = \mathrm{e}^{-\left(\frac{\mathrm{x}-52.5}{15.8}\right)^2} \quad (6)$$

In the indexes of the civil aircraft, the requirement of icing environment is usually expressed as: maximum icing thickness is D_{max}, which belongs to the index of unilateral constraint. Therefore, according to the actual situation, we can first determine its boundary default parameters or expected values, and then determine its membership function. Generally, we can choose the lower boundary$D_{min} = 0mm$, at this time, the icing environment will not affect the performance of the civil aircraft. Follow the approach to decide the bilaterally constrained indicators, we select $a = 6.5\text{mm}, \sigma = \frac{D_{max}}{6}$, thus, the membership function of the icing environment is:

$$A_3(x) = e^{-\left(\frac{6(x-6.5)}{D_{max}}\right)^2} \quad (7)$$

According to the suggested ice thickness of 13mm (or the related technical documents) in the laboratory climate experiment condition of the civil aircraft, the membership function of the icing environment in this study is:

$$A_3(x) = e^{-\left(\frac{x-0.5}{2.2}\right)^2} \quad (8)$$

Assuming that the climate test of an aircraft is carried out with relevant technical documents, including high temperature (40 ℃), low temperature (- 20℃) , relative humidity (95%) and icing thickness (5mm) , the civil aircraft works well in these conditions .For the convenience of calculation, it is assumed that the test indexes of an aircraft meet the requirements in the above test process, the membership factors of each factor are:

$$A_1(x) = 0.847,\ A_2(x) = 0.933,\ A_{,3}(x) = 0.244 \quad (9)$$

It is assumed that the weight of the three environments is obtained by AHP.

Analyze the number and proportion of all kinds of weather factors, the number of accidents every five years, the damage degree of the accident plane, the casualties on the plane, the aircraft manufacturer, the proportion of direct and indirect factors, the accident type, the statistics of the operator, etc.,Table2 is obtained.

Table2 Statistics of aviation accidents caused by various types of extreme weather

Weather type	Navigation (part 91)	Passenger and Freight Transport (121 units)	Total
Cold	13	5	18
Hot	12	8	20
Humidity	15	10	35
Icing	1003	6	1009

Through the table analysis, it can be seen that the damage caused by ice as a bad environmental factor is much higher than that caused by temperature and humidity as a bad environmental factor. The definite factors are high temperature, low temperature and freezing.

So determine the judgment Matrix A=$\begin{bmatrix} 1 & 1 & 1/2 \\ 1 & 1 & 1/2 \\ 2 & 2 & 1 \end{bmatrix}$, The weight vector of high temperature, low temperature and icing is obtained by solving the characteristic equation.

$$W = [0.25, 0.25, 0.5] \quad (10)$$

$$AW = A_1 w_1 + A_2 w_2 + A_3 w_3 = 0.578 \quad (11)$$

The climatic environmental adaptability of an aircraft as a whole can be expressed by means of this standard. If we divide the environmental adaptability of an aircraft into five classes {0,1,2,3,4} , where 0 means the non-adaptive environment, when AW belongs to the range (0,0.15] , the product's grade is 1; when AW belongs to the range (0.15,0.5] , the product's grade is 2; when AW belongs to the range (0.5,0.75] , the product's grade is 3; when AW belongs to the range (0.75,1] , the product's grade is 4. According to the calculation, the adaptability level of the civil aircraft is 3 grades, and the adaptability is good.

4. Conclusions

Through the analysis, it shows that the level of climate and environment adaptability of the civil aircraft can be evaluated by using the analytic hierarchy process and the integrated fuzzy theory . The evaluation results can be used to improve the capability and design of civil aircraft. We can also expand the flight envelope of civil aircraft and expand the civil aircraft market according to the actual situation.

5. Copyright Statement

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