Evaluation and analysis of civil aircraft flight test safety management capability based on matter element extension theory

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ABSTRACT

According to incomplete statistics, from 2001 to 2018, the number of Chinese civil aviation passengers has maintained an annual growth rate of 15% to 17.4%, and the national flight volume has increased by about 8% year-on-year.The rapid growth of air travel has accelerated the development of the civil aviation industry.Aviation safety has always been a focus of attention in the industry. With the continuous development of China's aviation industry, the aviation manufacturing industry in China is also growing, and the business volume of aircraft manufacturing and aircraft test flights is also rapidly increasing. How to ensure the safety of civil aircraft test flights is becoming a focus of active research in the industry.Safety is the bottom line and cornerstone of flight testing. When safety issues arise, they often lead to unimaginable disasters, and even lead to the failure of the entire model development.The test flight safety management system is an important means to ensure test flight safety. By systematically analyzing the various elements of the test flight safety management system, a test flight safety management capability evaluation model is established based on the matter element extension theory. The test flight safety management capability of the test flight unit is evaluated, and improvement strategies are sought, providing reference for airlines and test flight units to continuously improve their safety management level.

Keywords: Matter element extension theory; Civil aircraft test flight safety management; Safety management capability evaluation

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Seventh International Conference on Mechatronics and Intelligent Robotics (ICMIR 2023), edited by Srikanta Patnaik, Tao Shen, Proc. of SPIE Vol. 12779, 1277910 · © 2023 SPIE · 0277-786X · Published under a Creative Commons Attribution CC-BY 3.0 License · doi: 10.1117/12.2688666

1. INTRODUCTION

Civil aircraft flight test is an exploratory and pioneering engineering activity. With certain uncertainties and dangers, flight test safety risk management must be carried out, risks must be identified, and corresponding measures to avoid and reduce risks must be formulated and implemented to control risks within an acceptable range.With the development and popularization of software, hardware, and network technology, people's access to information is no longer limited by time and space.As long as there is Internet, they can obtain information through electronic devices and pass it on to others anytime and anywhere [1].The safety of a country's aviation production and operation activities is not only related to the efficiency and efficiency of aviation itself, but also to the life and property of the country and people, with a wide range of social impacts. Air transportation safety is a reflection of a country's economic development and social civilization. Ensuring the safety of all passengers and air transportation personnel is an important symbol of social justice, safety, civilization, and healthy development [2].Therefore, the safety of civil aircraft flight tests is extremely important, and flight safety management is also placed in a crucial position.The civil aviation industry is the industry that best reflects the comprehensive national strength and technological development level of the times.It has the characteristics of high technical equipment level, high capital intensity and high operational risk. Its system security has both similarities and particularities compared to other industries and enterprises [3]. Similarly, civil aircraft test flight is a complex task that requires the collaboration and cooperation of multiple disciplines and departments. Conducting civil aircraft test flight safety management requires rich professional knowledge and experience, and civil aircraft test flight safety management capabilities need to be continuously improved in practice and research to adapt to the increasing needs of civil aircraft test flight. In the field of civil aircraft flight testing, safety management started relatively late. By drawing on excellent practices in the industry, we have carried out the construction of a safety management system and continuously improved our safety management capabilities.In addition, multiple scholars have proposed different solutions for improving civil aviation safety management, and Tang Lanjian proposed strengthening the application of big data analysis in civil aviation safety management [4]. In terms of evaluating safety management capabilities, Wang Yonggang et al. conducted systematic research on civil aviation safety supervision capabilities using the principles of system dynamics, and proposed improvement directions for improving civil aviation safety supervision capabilities [5]. Based on the safety management system constructed by current civil aircraft test flight units, establish an evaluation index system for civil aircraft test flight management capabilities.By utilizing the theory of matter element extension, a model for evaluating the safety management capability of civil aircraft test flights is constructed, and the weak points of civil aircraft test flight safety management are identified. Strategies for improving the safety management capability of civil aircraft test flights are proposed, which can provide new control ideas for civil aircraft test flight safety management.

2. OVERVIEW OF SAFETY MANAGEMENT CAPABILITY EVALUATION FOR CIVIL AIRCRAFT TEST FLIGHTS

2.1 Civil aircraft flight test safety management system

Some flight test institutions in China and abroad are also conducting flight safety risk management based on their own understanding, mostly drawing on the safety management concepts of the national aviation industry to carry out flight safety management.The typical flight safety management system in China consists of four components and a total of twelve elements.The four components are security policies and objectives, security risk management, security assurance, and security promotion.Safety policies and objectives include safety management commitments and responsibilities, safety accountability, appointment of key safety personnel, coordination of emergency plans, and safety management system documents.Safety risk management includes hazard identification, safety risk assessment and mitigation measures.Safety assurance includes monitoring and evaluation of safety performance, change management, and continuous improvement.Safety promotion includes training and education, as well as safety communication.The safety management system for civil aircraft test flights is shown in Figure 1.

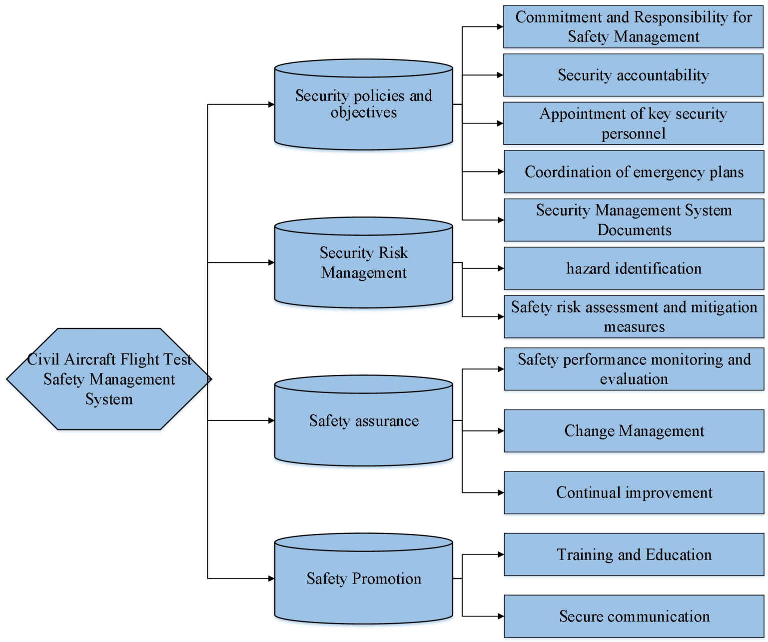

Figure 1. Civil Aircraft Flight Test Safety Management System

The core of the flight test safety management system is safety risk management. The flight test safety risk can be effectively reduced by continuously carrying out hazard identification, carrying out safety risk assessment and developing risk reduction measures.At the same time, safety management needs to be carried out systematically. Currently, the risk management of the test flight unit has completed preliminary construction, and there are still obvious shortcomings in areas such as safety training and safety culture construction.Civil aircraft test flight units can meet the requirements of test flight safety management by establishing a test flight safety management system and applying it in practice. However, there is still a certain gap between the test flight safety management level and the overall safety management level of civil aviation, and further research and improvement are needed.

2.2 Evaluation indicators for safety management capability of civil aircraft flight test

By analyzing the methods of civil aircraft test flight units to carry out safety management, the evaluation indicators of civil aircraft test flight safety management capability are constructed according to the 12 elements of the civil aircraft test flight safety management system, namely safety management commitment and responsibility, safety accountability, appointment of key safety personnel, coordination of emergency plans, safety management system documents, hazard identification, safety risk assessment and mitigation measures, safety performance monitoring and evaluation, change management Continuous improvement, training and education, and safety communication.At the same time, in order to facilitate the evaluation of indicators, the corresponding indicators were adjusted and optimized in combination with the actual situation of the flight test unit, and finally determined as the implementation of safety responsibilities, safety rewards and punishments, safety organization, flight test emergency manual, safety management system documents, hazard identification, flight test risk assessment and risk reduction measures, safety performance evaluation, change management, safety training, safety culture construction and continuous improvement.

3. EVALUATION AND ANALYSIS OF CIVIL AIRCRAFT FLIGHT TEST SAFETY MANAGEMENT CAPABILITY BASED ON MATTER ELEMENT EXTENSION THEORY

3.1 Matter element extension theory

In the selection of evaluation methods for the safety management capability of civil aircraft test flights, the general evaluation method defines weights and builds models, with the key difference being the determination of weights [6]. It can be mainly divided into three types: subjective weighting method: AHP, fuzzy comprehensive evaluation, etc.Objective weighting methods: entropy method, factor analysis method, neural network method, etc.Subjective and objective joint weighting methods: compromise coefficient comprehensive weighting method, linear weighted single objective optimization method, etc.The above methods can all make appropriate evaluations, but the drawback is that they cannot determine the trend of evaluation level changes. Therefore, this article introduces the matter element extension evaluation method.

The matter element extension method studies matter elements and their transformations using extension sets and matter element theory, using a formal tool to solve complex problems from a qualitative and quantitative perspective.It is a method that takes the indicator system and its characteristic values as matter elements, determines the evaluation level and measured data, calculates the classical domain, nodal domain, and correlation degree, and conducts quantitative analysis.

A matter-element is a triplet of things, features, and their values related to that feature， Expressed as $R=(N,C,V)$, N refers to things， C refers to the name field of a feature, V refers to value range of N versus C.

N features *(C1, C2,..., Cn)*, The matrix composed of the quantity values V_i（i=1,2,…,n） corresponding to the feature Ci（i=1,2,…,n） is shown in equation (1),referred to as n-dimensional matter elements:

$$R=(N,C,V)=\begin{bmatrix} N & C_1 & V_1 \\ & C_2 & V_2 \\ & \vdots & \vdots \\ & C_n & V_n \end{bmatrix} \tag{1}$$

3.2 Evaluation model of civil aircraft flight test safety management capability based on matter element extension theory

According to the matter element theory mentioned in 3.1, the classical domain matter element is defined as follows:

$$R_j=\left(N_j,\quad C_i,\quad V_{ij}\right)=\begin{bmatrix} N_j, & c_1, & v_{j1} \\ & c_2, & v_{j2} \\ & \vdots & \vdots \\ & c_n, & v_n \end{bmatrix}=\begin{bmatrix} N_j, & c_1, & \langle a_{j1}, & b_{j1}\rangle \\ & c_2, & \langle a_{j2}, & b_{j2}\rangle \\ & \vdots & & \vdots \\ & c_n, & \langle a_n, & b_n\rangle \end{bmatrix} \tag{2}$$

Among them,R_j is the jth token element of civil aircraft test flight safety management capability;N_j is the jth level of civil aircraft test flight safety management capability (j=1,2,3,4,5);C_i is the indicator corresponding to the evaluation level N_j,it is the i-th evaluation indicator for the safety management capability of civil aircraft flight test (i=1, 2,..., n; in this article,n is 12);V_{ij} is the magnitude range of C_i,the range of N_j with respect to the corresponding indicator C_i is called the classical domain R_j,a_{ji} and b_{ji} refer to the upper and lower limits of c_i values at level j.

The maximum and minimum values of all levels of each indicator range are taken, which is the material element R_p of the civil aircraft test flight safety management capability section:

$$R_p=\left(N_p,\quad C_i,\quad V_{ij}\right)=\begin{bmatrix} N_p, & c_1, & v_{p1} \\ & c_2, & v_{p2} \\ & \vdots & \vdots \\ & c_n, & v_n \end{bmatrix}=\begin{bmatrix} N_p, & c_1, & \langle a_{p1}, & b_{p1}\rangle \\ & c_2, & \langle a_{p2}, & b_{p2}\rangle \\ & \vdots & & \vdots \\ & c_n, & \langle a_n, & b_n\rangle \end{bmatrix} \tag{3}$$

Among them, N_p is the value range of all evaluation levels of each index of civil aircraft flight test safety management ability.v_{pi}=(a_{pi}, b_{pi}) is the magnitude range of N_p for c_i,the nodal domain of N_p,a_{pi} and b_{pi} are the maximum and minimum values of each indicator in each level.

For the safety management ability of civil aircraft test flight of the evaluation object N_o, the collected data and analysis results are represented by matter element, and the matter element R_o to be evaluated is as follows:

$$R_o = (N_o, \quad C, \quad V) = \begin{bmatrix} N_o, & c_1, & v_1 \\ & c_2, & v_2 \\ & \vdots & \vdots \\ & c_n, & v_n \end{bmatrix} \tag{4}$$

Where, v_i is the quantitative value of N_o about c_i, that is, the specific value of the index to be evaluated.

Correlation degree $k_j(v_i)$ can express the subordination relationship between things and reflect the degree to which each index of civil aircraft flight test safety management ability belongs to a certain level.The correlation degree of the *i*-th index of the evaluation object with respect to the *j*-th level is calculated as follows:

$$k_j(v_i) = \begin{cases} \dfrac{-\rho(v_i, v_{ji})}{|v_{ji}|} & (v_i \in V_{ji}) \\ \dfrac{\rho(v_i, v_{ji})}{\rho(v_i, v_{pi}) - \rho(v_i, v_{ji})} & (v_i \notin V_{ji}) \end{cases} \tag{5}$$

Among them:

$$\rho(v_i, v_{ji}) = \left| v_i - \frac{1}{2}(a_{ji} + b_{ji}) \right| - \frac{1}{2}(b_{ji} - a_{ji}) \tag{6}$$

$$\rho(v_i, v_{pi}) = \left| v_i - \frac{1}{2}(a_{pi} + b_{pi}) \right| - \frac{1}{2}(b_{pi} - a_{pi}) \tag{7}$$

Among them, v_i is the value of the object element to be evaluated;v_{ji} is a classical range of material element quantities;v_{pi} is the range of nodal material element quantities; $\rho(v_i, v_{ji})$ is the distance between point v_i and v_{ji}; $\rho(v_i, v_{pi})$ is the distance between point v_i and v_{pi}.

4. MODEL INSTANCE VALIDATION

A civil aircraft test flight unit has established a test flight safety management system by referring to the safety management concept of civil aviation industry and combining with the actual needs of test flight. By constructing system documents, the system documents are continuously applied to the test flight site. After continuous practice, a relatively perfect test flight safety management method has been established and certain test flight safety management capabilities have been obtained.Therefore, it is more appropriate to consider a certain test flight unit as the research object of this case.Through on-site research, the 12 indicators of the flight safety management system of a certain test unit were divided into 5 levels, Nj={high, high, average, low, very low}, and the level of each indicator was represented using a five point system.According to equation (2), the classic domain element for constructing the civil aircraft test flight safety management capability of a certain test flight unit is[7-10]:

$$R_j = \begin{bmatrix} & N_1 & N_2 & N_3 & N_4 & N_5 \\ c_1 & (4,5] & (3,4] & (2,3] & (1,2] & (0,1] \\ c_2 & (4,5] & (3,4] & (2,3] & (1,2] & (0,1] \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ c_{12} & (4,5] & (3,4] & (2,3] & (1,2] & (0,1] \end{bmatrix} \tag{8}$$

According to equation (3), the nodal element of the civil aircraft test flight safety management capability of a certain test flight unit is calculated as:

$$R_p = [P \quad C_n \quad [0,5]] \tag{9}$$

Through the investigation of related departments of safety and test flight organization of the test flight unit, 5 experts were invited to score 12 indicators in the index system. The expert group was composed of 2 managers of the test flight unit, 2 front-line test flight staff and 1 retired expert in test flight.The final score is averaged and the weight of the expert is the same.According to the above formula, the matter-element value of each evaluation index of the safety management ability of civil aircraft in a test flight unit is calculated after summary, and the results are shown in Table 1.

Table 1. Subject matter element value of each evaluation of safety management ability of civil aircraft in a test flight unit

Index	c_1	c_2	c_3	**…**	C_{10}	C_{11}	C_{12}
Matter element value	2.813	4.135	3.214	…	3.552	3.132	4.164

According to equations (5), (6), and (7), the correlation degree of various evaluation indicators for the safety management capability of a certain test flight unit's civil aircraft test flight can be calculated, as shown in Table 2.

Table 2. Correlation degree of various evaluation indicators for the safety management capability of civil aircraft test flights of a certain test flight unit with respect to each level

Evaluating indicator	**Correlation degree of each level**				
	N_1	N_2	N_3	N_4	N_5
c_1	-0.350	-0.032	0.147	-0.238	-0.428
c_2	0.031	-0.023	-0.427	-0.572	-0.638
c_3	0.015	-0.027	-0.418	-0.471	-0.829
c_4	0.243	-0.251	-0.542	-0.762	-0.721
c_5	0.123	-0.132	-0.467	-0.723	-0.763
c_6	-0.415	-0.317	0.112	-0.316	-0.552
c_7	-0.220	0.133	-0.042	-0.344	-0.543
c_8	-0.124	0.243	-0.114	-0.452	-0.597
c_9	-0.157	0.270	-0.119	-0.437	-0.543
c_{10}	-0.303	0.237	-0.145	-0.423	-0.664
c_{11}	-0.343	0.023	-0.022	-0.323	-0.513
c_{12}	-0.323	0.063	-0.011	-0.334	-0.567

Through evaluation, the various indicators of the civil aircraft test flight safety management capability of the test flight unit are rated as follows, with indicators $c_1$and c_6 at the "average" level; Indicators c_2,c_3,c_4,and c_5 are in the "excellent" level; The other indicators are at the "good" level, and the overall result is in line with the actual situation of the evaluation object.Through this analysis, it shows that the flight test unit has weak links in the implementation of safety responsibilities and the identification of hazard, and needs to further consolidate the safety foundation.In addition, it is necessary to increase management efforts in the construction of safety culture and safety training to promote the continuous improvement of safety management capabilities.

5. CONCLUSION

With the continuous development of China's civil aircraft manufacturing industry, civil aircraft test flights will be in an increasingly prominent position. The safety of civil aircraft test flights will face enormous tests and challenges.As a naturally risky operational activity, flight test safety needs to be taken seriously by all practitioners.Through systematic analysis of the flight safety management system, an evaluation index system for flight safety management capability is proposed, and a capability evaluation model based on matter element extension theory is constructed. Combined with the actual situation of a certain unit, a civil aircraft flight safety management capability evaluation is carried out, pointing out the weak points and improvement directions of flight safety management, and providing reasonable suggestions for the continuous improvement of flight safety management capability.The flight test safety management system is constantly developing and optimizing. For example, at present, the industry is speeding up Digital transformation and relying on data platform to manage civil aircraft flight test safety, which will greatly save the energy of safety management personnel.In the future, the evaluation index system for flight safety management capability can be further optimized, and other suitable evaluation methods can be selected for further evaluation of flight safety management capability.At the same time, evaluation research can be conducted on different flight test units for reference.The evaluation model mentioned in this article can also be used in the field of civil aviation, facilitating the interaction between civil aircraft test flights and safety management in the civil aviation industry, and promoting the continuous improvement and enhancement of safety management in the civil aviation industry and test flights.

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