Optimization of the flight test organization structure of batch-produced aircraft based on entropy theory

Deng Jun

1Commercial Aircraft Flight Test Center of COMAC, Shanghai, China

*Corresponding author: dengjun@comac.cc

Abstract. According to the characteristics of batch-produced aircraft flight test, this paper optimizes the traditional project-based organization structure, and innovatively proposes an organizational structure suitable for batch-produced aircraft test flight. Using entropy theory, an entropy model of flight test organization structure is established, and the model is used for calculation and analysis to provide quantitative data reference for the optimization of flight test organization structure.

Keywords: entropy, flight test, organizational structure, commercial aircraft.

1. Introduction

Commercial aircraft can be put into mass production after completing development and certification flight test task and obtaining the Type Certificate. The commercial aircraft project will be transferred from the development stage to the batch production stage. The flight test of the batch-produced aircraft is required before delivery to the customer. The purpose of the test flight is to verify the production of the aircraft and demonstrate the aircraft performance to the customer. In the development and certification flight test phase, the flight test organization structure adopts a project-based organization structure. But entering the batch production stage, with the increase in the number of aircraft delivered and the shortening of the delivery cycle, the project-based organization structure gradually cannot adapt to the high-frequency flight test.

Entropy is a concept that measures the uncertainty of random events. For the system, entropy is a measure of state chaos and disorder [1]. The larger the entropy value of the system, the more chaotic the system, and the smaller the entropy value of the system, the more orderly the system. In management science, entropy theory has become an effective tool in studying the orderliness of organizational structure and the flexibility to adapt to environmental changes [2]. Therefore, the entropy theory can be used to optimize the organization structure of the batch-produced aircraft flight test by combining the characteristics of the batch-produced aircraft flight test missions.

2. Entropy theory

For the information flowing in the organizational structure, people are most concerned about its timeliness, accuracy, and the ability to reconstruct information when the organization faces changes in the environment or external shocks [3, 4], which is timeliness $R_1$, quality $R_2$ and adaptability $R_3$. And use $R$ to represent the comprehensive index of organizational structure, the larger the $R$, the better.


\[ R = \alpha R_1 + \beta R_2 + \gamma R_3 \]  

Among them \( \alpha, \beta, \gamma \) are the weight coefficients of the influence of timeliness, quality and adaptability on the organization structure.

2.1. Timeliness of the organization

The timeliness of the organization represents the speed of information in the process of transmission in the organization, and the timeliness entropy represents the uncertainty of the speed of information flow in the process of information transmission between the elements of the organization [5]. The greater the timeliness entropy, the worse the timeliness of the organization; the smaller the timeliness entropy, the better the timeliness of the organization.

Assuming that there are \( n \) nodes in the organizational structure, the information flow within the organization is transmitted from top to bottom and from bottom to top. The length of the vertical connection between the \( i \)-th and \( j \)-th nodes is \( L_{ij} \), where \( i, j \in (1, n), i \neq j \). The length of the direct connection between the nodes is 1, and the length increases by 1 for each transfer. The total number of timeliness microstates of the organizational structure is

\[ A_1 = \sum_{i=1}^{n} \sum_{j=1}^{n} L_{ij} \]  

Maximum entropy of organizational structure is

\[ H_{1m} = \log_2 A_1 \]  

The probability of timeliness microstates in organizational structure is

\[ P_1(ij) = \frac{L_{ij}}{A_1} \]  

The total timeliness entropy of organizational structure is

\[ H_1(ij) = - \sum_{i=1}^{n} \sum_{j=1}^{n} P_1(ij) \log_2 P_1(ij) \]  

The timeliness of organizational structure is

\[ R_1 = 1 - \frac{H_1}{H_{1m}} \]  

2.2. Quality of the organization

The quality of the organization represents the accuracy of the information transmitted in the organization, and the quality entropy reflects the uncertainty of the information quality [6]. The greater the quality entropy, the worse the accuracy of the organization's information transmission; the smaller the quality entropy, the better the accuracy of the organization's information transmission.
Define the connection span of each node $K_i, i \in (1, n)$ is the number of nodes directly connected with the $i$-th node in the organizational structure. The total number of quality microstates of the organizational structure is

$$A_2 = \sum_{i=1}^{n} K_i$$

(7)

Maximum quality entropy of organizational structure is

$$H_{2m} = \log_2 A_2$$

(8)

The probability of quality microstate in organizational structure is

$$P_2(i) = \frac{K_i}{A_2}$$

(9)

The total quality entropy of organizational structure is

$$H_2 = \sum_{i=1}^{n} -P_2(i)\log_2 P_2(i)$$

(10)

The quality of organization structure is

$$R_2 = 1 - \frac{H_2}{H_{2m}}$$

(11)

2.3. Adaptability of the organization

The adaptability of the organization is the ability to reconstruct information after being disturbed when the information is transmitted in the organization. And the diversification entropy reflects the measurement of the uncertainty of information circulation. The larger the diversification entropy, the weaker the organization's ability to reconstruct information and the poorer its adaptability to changes in the external environment. The smaller the diversification entropy, the stronger the ability of the organization to reconstruct information and the stronger the adaptability to changes in the external environment.

Define the horizontal connection length of the $i$-th and $j$-th nodes in the same layer as $F_{ij}$. All the contacts issued by node $i$ are the initiative connections $f_1$. All the first-step contacts sent from node $i$ are the effective initiative connections $f_2$. And the rest connection are the change connection [7]. The total number of diversification microstates in the organization structure is

$$A_3 = \sum \sum F_{ij}$$

(12)

The maximum diversification entropy of organizational structure is

$$H_{3m} = \log_2 A_3$$

(13)

The probability of diversification microstate in organizational structure is
The total diversification entropy of organizational structure is

\[ H_3(ij) = - \sum \sum P_3(ij) \log_2 P_3(ij) \]  

The adaptability of organizational structure is

\[ R_3 = 1 - \frac{H_3}{H_{3m}} \]  

3. Organizational structure optimization

The characteristics of the flight test in the development stage are: long flight test cycles, many flight test subjects, and many specialties involved. And Flight test tasks undertaken by different prototype aircrafts are quite different. Therefore, in the commercial aircraft development stage, a project-based organization structure is usually adopted, and the Aircraft Team is responsible for the organization and implementation of the flight test task of the aircraft, as shown in Figure 1. Since the members of the aircraft team are relatively fixed, the pilots, flight test engineers, and operations control engineer in the aircraft team have a clearer understanding of the aircraft status, technical issues and flight schedule.

![Figure 1. Organization structure and Tree diagram before optimization](image)

The characteristics of the flight test in the batch production stage are: short test flight cycle, fewer flight test subjects, less specialties involved, high similarity of tasks for different delivery aircraft, and a large number of aircraft need to be tested in the same period. So the advantages of the Aircraft Team cannot be reflected in the batch production stage, and relatively fixed Aircraft Team members will cause a waste of resources, and it is difficult to meet the needs of multiple batch-produced aircraft to carry out flight test in parallel.

Therefore, the organizational structure in the development phase need to be optimized, and an organizational structure of "Aircraft Management Team + Public Resource Team" is formed, as shown in Figure 2. The Aircraft Management Team here is a simplification of the original aircraft team, which separating the pilot, operations control engineer, and flight support engineer from the aircraft team, Distinguishing exclusive resources and public resources, so that public resources can be configured more flexibly. It can solve the problems of low work efficiency and resource shortage.

\[ P_3(ij) = \frac{f_1 - f_2}{A_3} \]
According to the organization structure entropy model, the following results are obtained by calculating the organization structure entropy of the aircraft team before and after optimization:

**Table 1. Timeliness of organization structure before and after optimization**

| Organizational structure | Vertical connection length | $P_1(ij)$ | Connection symbol | Microstates |
|--------------------------|---------------------------|----------|------------------|-------------|
| Before optimization      | 1                         | 1/84     | 1-2,1-3,1-4,2-5,2-6,2-7,3-8,3-9,3-10,4-11,4-12,4-13,5-14,6-15,7-16,8-17,9-18,10-19,11-20,12-21,13-22 | 21          |
|                          | 2                         | 2/84     | 1-5,13,2-14,16,3-17,19,4-20,22                | 36          |
|                          | 3                         | 3/84     | 1-14,22                                                   | 27          |
| Result                   |                           |          | $H_{1m} = 6.3923$, $H_1 = 5.4542$, $R_1 = 0.1467$     |             |
| After optimization       | 1                         | 1/108    | 1-2,4,5,7,3-5,7,4-5,7-8,10,6,6,11,13,7-14,16       | 21          |
|                          | 2                         | 2/108    | 1-5,7,2,8,16,3,8,16,4,8,16                         | 60          |
|                          | 3                         | 3/108    | 1-8,16                                                   | 27          |
| Result                   |                           |          | $H_{1m} = 6.7548$, $H_1 = 5.8030$, $R_1 = 0.1409$     |             |

**Table 2. Quality of organization structure before and after optimization**

| Organizational structure | Connection span | $P_1(ij)$ | Connection symbol | Microstates |
|--------------------------|-----------------|----------|------------------|-------------|
| Before optimization      | 1               | 1/42     | 14-22            | 9           |
|                          | 2               | 2/42     | 5-13             | 18          |
|                          | 3               | 3/42     | 1                | 3           |
|                          | 4               | 4/42     | 2-4              | 12          |
| Result                   |                 |          | $H_{2m} = 5.3923$, $H_2 = 4.2791$, $R_2 = 0.2064$     |             |
| After optimization       | 1               | 1/42     | 8-16             | 9           |
|                          | 3               | 3/42     | 1                | 3           |
|                          | 4               | 4/42     | 2-4              | 12          |
|                          | 6               | 6/42     | 5-6              | 18          |
| Result                   |                 |          | $H_{2m} = 5.3923$, $H_2 = 3.5998$, $R_2 = 0.3324$     |             |
Table 3. Adaptability of organization structure before and after optimization

| Organizational structure | Horizontal connection length | $P_{ij}$ | Connection symbol | Diversification microstate |
|--------------------------|-----------------------------|----------|-------------------|--------------------------|
| Before optimization      | 2                           | 1/330    | 2-3, 2-4, 3-4, 5-6, 5-7, 6-7, 7-8, 8-9, 8-10, 9-10, 11-12, 11-13, 12-13 | 12                        |
|                          | 4                           | 3/330    | 14-15, 14-16, 15-16, 16-17, 17-18, 18-19, 19-20, 21-20, 22-21, 22-5-8, 7-8, 8-9, 9-10, 10-11, 11-13, 13-10, 11-13 | 108                       |
|                          | 6                           | 5/330    | 14-17, 14-17, 17-17, 17-16, 16-17, 17-16, 16-20, 16-22, 18-20, 20-22, 18-20, 20-22, 18-20, 22 | 135                       |
| Result                   |                             |          |                   | $H_{3m} = 8.3663$, $H_3 = 4.9963$, $R_3 = 0.4028$ |
| After optimization       | 2                           | 1/138    | 2-3, 2-4, 3-4, 5-6, 5-7, 6-7, 7-8, 8-9, 8-10, 9-10, 11-12, 11-13, 12-13, 14-15, 14-16, 15-16 | 15                        |
|                          | 4                           | 3/138    | 8-11, 8-11, 11-11, 11-10, 10-11, 11-16, 16-14, 14-16, 16-14, 16-14, 14-16, 16-14, 16-14 | 51                        |
| Result                   |                             |          |                   | $H_{3m} = 7.1085$, $H_3 = 4.0147$, $R_3 = 0.4352$ |

Table 4. Index of organization structure before and after optimization

| Organizational structure | Timeliness $R_1$ | Quality $R_2$ | Adaptability $R_3$ | comprehensive index $R$ |
|--------------------------|------------------|---------------|-------------------|-------------------------|
| Before optimization      | 0.1467           | 0.2064        | 0.4028            | 0.2520                  |
| After optimization       | 0.1409           | 0.3324        | 0.4352            | 0.3028                  |

From the above calculation results, it can be seen that although the timeliness of information transmission in the organizational structure before optimization is better. The accuracy of information transmission in the organizational structure after optimization and the flexibility to resist external environmental interference are better. When the weight coefficients $\alpha, \beta, \gamma$ of the influence of timeliness, quality and adaptability on the organizational structure are the same, the comprehensive index of the optimized organizational structure is higher.

4. Conclusions
The development of civil aircraft is mainly divided into five stages: demand and concept demonstration, preliminary design, detailed design, trial production and verification, and mass production. The work of different stages will have corresponding characteristics, so there will be the most suitable organizational structure. This paper mainly considers the implementation of flight test in civil aircraft trial production and verification, and mass production. Based on the entropy theory model, the flight test organization structure is optimized according to the characteristics of flight test work in different stages. The optimized organization structure has been used in actual work, effectively improving the efficiency of flight test organization.

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