The Research on Redundant Design in Civil Aircraft Design

Bing Cheng

1Shanghai Aircraft Design and Research Institute, Shanghai 201210, China

E-mail: chengbing198805@163.com

Abstract. This article explores the redundant design in the design of civil aircraft. It’s based on the meaning of giving redundancy beyond the basic needs to the parts or the products by redundant design. And this article also conducts targeted research on several typical redundant design methods such as redundant design in sketch, redundant design steps in part, integrated design of parts, redundant parts in assembly and redundant assembly of the civil aircraft. The redundant design formulas corresponding to different design methods are obtained by analyzing specific design examples. It is found in the research that redundant designs and components are also effective ways to optimize the design of the structure and to pre-solve a series of problems that may appear in subsequent stages. Moreover, the realizations of the requirements are compared between the step-by-step redundant design and the integrated redundant design. And it is found that the step-by-step redundant design is a better design method.

1. Introduction

The concept of redundant design first appeared in the field of information technology, and its application is mostly used to improve the security of the design, such as improving the reliability of airborne electronic equipment [1] and flight controller [2]. Increasing the redundancy of the product includes two levels of meaning. One is to give redundancy beyond the basic needs, and the other is to provide additional backups in case of need [3].

For the civil aircraft, the pursuit of design optimization is a powerful way to reduce aircraft weight and enhance aircraft competitiveness. However, the optimization of part design does not mean the optimal design of components and products, and the optimal design does not mean the optimal manufacture and assembly. Sometimes in order to achieve the overall optimization of the product, it is necessary to add the redundant part to the component design. That is to say, the design elements that exceed the basic design requirements for components may be given to the components. It eventually produces local redundancy, such as increasing weight, occupying more space, increasing complexity, extending design and manufacturing time, and also increasing costs [4], which is not a local optimal solution. However, for the product as a whole, the redundant design of this part has optimized the design and manufacture for the product. In addition, local redundancy is more reliable than overall redundancy, so the redundant design should start from the most basic units [5].

2. Redundant design

Based on the meaning of the first level of redundant design in other fields, combined with civil aircraft design, the concept of redundant design is given: in the design of parts, in order to carry out further design upgrades in the future, and in product design, to improve the benefits of manufacturing, assembly or operations in subsequent product life cycle, some redundant design elements are added at
the beginning of the design. It’s beyond the basic design requirements of product design and may cause local redundancy. However, it plays a role in optimizing the design, manufacturing and operational benefits of the overall product.

Redundant models are defined as: product parts are kept in a semi-open or semi-finished state in the design, or design functions or structures that are not basic requirements of product design are attached to provide openings for future design, manufacturing, assembly and operation.

It means that the core of the design is fixed, but the intermediate state of the design can be redefined according to future design needs. We can design the known for the unknown. The part is designed for the product. And the product is designed for its life cycle.

3. Redundant design in sketch

Many parts are designed based on sketches. Sketch information can be selectively expressed in part design. During the sketch design process, design elements can be given to the sketch as many as possible. That is, redundant design is performed in the sketch. It will not only meet the basic design requirements of this part, but also meet the needs of part configuration changes and modifications in the future. For example, the sketch can exceed the design scope of the part instance in the design of the frame, as shown in figure 1. The complete sketch can meet the design requirements of the part in different stations and configurations. The basic design requirements of the part are achieved through feature removal during part design. It facilitates design modifications, improves the convenience of design, simplifies the design process and avoids redundant structures in the physical parts.

![Figure 1. Comparison of the part and its complete sketch.](image)

The corresponding redundant design formula can be summarized as:

\[ S = S_0 + S_r \]

4. Redundant design steps in part

In the part design process, some redundant design steps that are meaningless to a single part can be added to achieve design optimization. For example, in the longitudinal joint area of the fuselage, the stringer connection is generally achieved by the stringer joints. They are designed by parametric method to control the longitudinal length of stringer joints with uniform numerical parameters. This can already realize the modular design of the stringer joints. But for the stringer joints in the joint area of the contracting skins, the seemingly unified design method will lead to the result that the uniformity of the length of the stringer joints is limited to the equidistant points, due to the contracting skins and the edge fillet treatment of the stringers. And the equidistant point will disappear on the part structure.
because the stringer joint is rounded to avoid interference with the stringer, as shown in figure 2. This will eventually lead to a result that the stringer joints are not the same distance from the frame plane by the seemingly unified design way. As shown in table 1, the distances of stringer joints from the frame plane at different positions of L1 to 42 are shown. The distance between the equidistant points and the frame plane is 152.5mm. The maximum deviation is about 1.4mm, which brings a certain degree of confusion to subsequent assembly work. In order to solve this problem, a design step is added in the design process of the stringer joint. The tail of the stringer joint is trimmed through the parallel plane of the frame plane, as shown in figure 3. In the figure, line A is the boundary without redundant design, and line B is the boundary with redundant design. And through uniform repair, the consistency of the distances between the tail of the stringer joints and the frame plane is ensured, which facilitates uniform tooling positioning of dozens of stringer joints here during assembly.

**Figure 2.** Equidistant points generated during the design of stringer joints.

**Table 1.** Distances of stringer joints from the frame plane at different positions of the contracting skin.

| Stringer | Distance(mm) | Stringer | Distance(mm) | Stringer | Distance(mm) |
|----------|--------------|----------|--------------|----------|--------------|
| L1       | 152.441      | L15      | N/A          | L29      | 151.703      |
| L2       | 152.441      | L16      | 152.168      | L30      | 151.676      |
| L3       | 152.434      | L17      | 152.152      | L31      | 151.723      |
| L4       | 152.414      | L18      | 152.500      | L32      | 151.129      |
| L5       | 152.426      | L19      | 152.094      | L33      | 151.621      |
| L6       | 152.379      | L20      | 152.063      | L34      | 151.605      |
| L7       | 152.363      | L21      | N/A          | L35      | 151.578      |
| L8       | 152.336      | L22      | 151.953      | L36      | 151.547      |
| L9       | 152.316      | L23      | 151.922      | L37      | 151.539      |
| L10      | 152.285      | L24      | 151.883      | L38      | 151.535      |
| L11      | 152.258      | L25      | 151.844      | L39      | 151.535      |
| L12      | 152.234      | L26      | 151.805      | L40      | 151.539      |
| L13      | 152.215      | L27      | 151.770      | L41      | 151.547      |
| L14      | 152.197      | L28      | 151.738      | 42       | 151.547      |
Figure 3. The boundary of the stringer joint.

The corresponding redundant design formula can be summarized as:

$$PS = PS_0 + PS_r$$

(2)

$PS$ represents the part design steps which contain the steps meet basic design requirements as $PS_0$ and redundant steps as $PS_r$.

5. Integrated design of parts

A certain part needs to be designed due to specific function and structure. When designing, it’s tried to avoid additional structures that exceed the basic function. However, when two or more parts are in conflict or close to each other during layout, combine multiple parts into one by integrated design. Although redundant structures may be added to a single part, the layout and design of parts in a local area have achieved an optimized effect.

For example, the trunk bracket and the stringer joint can be integrated to design, so that a single part could have the functions and necessary structures of both parts, as shown in figure 4. For each of the original parts, some structures of the new design are redundant. But it is an optimized design that not only reduces weight, but also guarantees the necessary functions and structures for the both.

Figure 4. Integrated design of the trunk bracket and the stringer joint.

The corresponding redundant design formula can be summarized as:

$$P = P_1 + P_2 = P_0 + P_r$$

(3)

$P$ represents the part which contains key structures of different parts as $P_1$ and $P_2$. One part, denoted by $P_r$, is redundant for the other, denoted by $P_0$.

6. Redundant parts in assembly

In some areas with complex assembly conditions, such as those involving multi-layer connections, the length of the fasteners varies due to the thickness of the connected structure, which can easily lead to the wrong selection of fasteners during subsequent assembly. The length of the fasteners can be unified by adding some parts, such as redundant shim, as shown in figure 5.
These parts are not basic design requirements and can be eliminated. However, the length of the fasteners installed here can be unified by adding the shim. It simplifies the assembly and avoids the wrong arrangement of the fasteners during assembly.

The corresponding redundant design formula can be summarized as:

\[ A = A_0 + P_r \]  

(4)

A represents the assembly which contains the assembly meets basic design requirements as \( A_0 \) and redundant part as \( P_r \).

7. **Redundant assembly**

The realization of the product has captured the stages of design, manufacturing, assembly and operation through requirements. The design cycle may take months or even more than a year. In fact, some of the customer's needs, such as the selection requirements of different internal structures, have little effect on the product's functional structure. Therefore, it is possible to provide diversified options in product design to simultaneously deliver to customers to choose from. For example, in the design of the cabin floor, a diversified design configuration of the seat track is added for customers to use in the selection of various seat configurations in subsequent operations, as shown in figure 6.

The corresponding redundant design formula can be summarized as:

\[ A = A_1 + A_2 = A_0 + P_r \]  

(5)

\( A \) represents the assembly which contains key structures of different assemblies as \( A_1 \) and \( A_2 \). One assembly, denoted by \( A_1 \), is redundant for the other, denoted by \( A_2 \). \( A \) can be chosen as \( A_1 \) or \( A_2 \).

For redundant design, redundant sketches, part design steps, parts and assemblies can be combined when necessary. The parts can be described as special assembly, denoted by \( P_r \subset A_0 \) and \( P_r \subset A_1 \). Therefore, the redundant design of the component can be expressed as follows.

\[ A = f(S_0, PS_0, A_0, S_r, PS_r, A_r) \]  

(6)

The logic diagram is shown in figure 7, and the degree of realization of the design process to requirements is recorded as \( R \).
If we first design for the basic design requirements, and then optimize the design for manufacturing, operations, etc., the logic diagram is shown in figure 8.

![Logic Diagram of Integrated Redundant Design](image)

**Figure 8.** Logic diagram of integrated redundant design.

\[
R_2 = 1 - (1 - R_{S_y} R_{PS_y} R_A)(1 - R_{S_y} R_{PS_y} R_A) \]

(11)

We will explore which design method is better.

\[
R_1 = R_{S_y} R_{PS_y} R_A = (R_{S_y} + R_{S_y} - R_{S_y} R_{S_y})(R_{PS_y} + R_{PS_y} - R_{PS_y} R_{PS_y})(R_{A_y} + R_{A_y} - R_{A_y} R_{A_y}) 
\]

(12)

\[
R_2 = 1 - (1 - R_{S_y} R_{PS_y} R_A)(1 - R_{S_y} R_{PS_y} R_A) = (R_{S_y} R_{PS_y} R_A) + R_{S_y} R_{PS_y} R_A - R_{S_y} R_{PS_y} R_A - R_{S_y} R_{PS_y} R_A 
\]

(13)

\[
R_1 - R_2 = (R_{S_y} + R_{S_y} - R_{S_y} R_{S_y})(R_{PS_y} + R_{PS_y} - R_{PS_y} R_{PS_y})(R_{A_y} + R_{A_y} - R_{A_y} R_{A_y}) 
\]

(14)

Because \(0 < R_{S_y} < 1\), \(0 < R_{S_y} < 1\), \(0 < R_{PS_y} < 1\), \(0 < R_{PS_y} < 1\), \(0 < R_{A_y} < 1\), and \(0 < R_{A_y} < 1\), we can get \(R_1 - R_2 > 0\). It means that the design method of step-by-step redundant design is better.

**8. Conclusions**

The purpose of redundant design is to pre-solve a series of problems that may appear in subsequent design upgrading, manufacturing, assembly and operation by adding some redundant information and structures during the design phase to give components some functional structures that exceed their...
basic design requirements. It could achieve design optimization at the product level or during the product life cycle to increase product competitiveness.

References

[1] Zhang Z W 2017 Redundancy design and reliability analysis of airborne electronic equipment Electro-optic Technology Application 32 66–69
[2] Wang Z Q and Gu X S Redundancy design on flight controller Journal of East China University of Science and Technology (Natural Science Edition) 35 158–162
[3] Jiao Z 2018 Theoretical and experimental research on the seismic redundancy design of reinforced concrete frame structure building [D] China Academy of Building Research
[4] Sun W W and Zhou H 2008 Effective redundant design Electronic Product Reliability and Environmental Testing 26 47–50
[5] Sun H Y 2007 Study on the relationship between redundancy design technique and reliability Chinese Journal of Scientific Instrument 28 2089–92