The Research on Indirect Modular Adaptable Design Platform on Part Design of Civil Aircraft

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Abstract. Based on the traditional modular design and the module division concept of virtual flexible modules in generalized modular design, this paper proposes a design method of indirect modular design. It suggests a way to achieve modular design of products without obvious serialization and hierarchical characteristics integrating modular platform and parameterized platform. The division and application of geometric parameters and numerical parameters of civil aircraft fuselage frame are taken as an example to show how it works. The indirect module is constructed on the basis of the framework model, and the lines and surfaces of the framework model are used as driving parameters. The design idea of adaptable design platform based on indirect modular design is also presented in this paper. The similar modules of the parameterized family modules can be designed quickly by driving the geometric parameters and numerical parameters separately. It makes faster and more accurate response to customer needs.

1. Introduction
The refinement and rapid increase of product requirements require us to have faster design methods to meet customer needs and win market competition. Modular design, as an effective method for serial and rapid design of products, has gradually developed from the early twentieth century and has been applied to many fields. However, the traditional modular design is mainly for products with obvious serialization and hierarchical characteristics. And then do parameterized design for the product or components to achieve modularization of product design. For many non-series products, it is not feasible to simply extract the parameters that can be designed in series at the part level.

However, the similar structure means that the part design steps are similar or there are many identical steps in the part design stage, which can be used as the basis for module division. This article introduces the concept of indirect modular design, expands the application field of modular design theory, and applies the product design platform based on indirect modular design to aircraft component design, further expounds the idea of indirect modular design.

2. Generalized modular design
Professor Y S Xu was the first to propose the concept of generalized modular design [1]. There are three types of the generalized modules, namely parameterized flexible module, virtual flexible module and flexible unit structure [2]. In a complex structural entity, part of its structure may be more standardized in terms of form and parameters, and has a relatively fixed sub-function. It can be further divided into different functional modules, but it cannot be divided in structure. Then comes the virtual flexible module. It only has the meaning of segmentation in CAD software.
3. Indirect modular design

Indirect modular design refers to analyzing the design ideas of product parts combining functional analysis, taking an intermediate state in the part design process as the object of modular design, introducing parametric design and variable analysis methods, dividing and constructing the indirect module and product platform with greater adaptability, and then realizing the rapid design of the product through the combination of indirect modules or the derivative of the product platform.

Indirect module is a structure with specific functions and a parameterized structure model. Its interface characteristics depend on the maturity of the indirect module. The maturity of the indirect module is defined as the completion of the indirect module from the final part. If the indirect module is the final module, its maturity is 1 and the interface feature is the interface of the product itself. Otherwise it is a collection of interfaces in the product and indirect module design process.

Indirect modular design is also a method to divide a structure part into different divisions in CAD software. Compared to the virtual flexible module, the module division of indirect module is based on the modeling ideas and steps, and the modules might not have fixed function in the final part. But they have some fixed function in the design process of the part. It doesn’t even show up in the final structure. But for mass similar parts, the indirect module and its parameterized family modules, namely flexible indirect module can be the common foundation for design.

The importance of indirect module division is not only to make modular design on some product which is hard to make serial design such as some parts of the civil aircraft, but also to divide the modules at design execution level.

In addition to this, flexible indirect module’ parameters mainly come from the points, lines and surfaces of the framework model composed of key design reference information such as points, lines and surfaces, supplemented by a set of values constrained by a certain size range. The main error correction process of the parameter is directed at geometric parameters, which are more convenient and intuitive. Compared to pure numerical parameters, they are more intuitive and easier to adjust.

It is intended to explore the regularity of features and designing ideas in part and product design, and realize the complete combination of regularity and difference. The product design process will go from realizing designing results to exploring rules. Parametric design is intended to emphasize the procedural nature of the design, the logic of the process, and the diversity of results [3].

The basis of the indirect modular design is the framework model, and the lines and surfaces of the framework model are used as driving parameters. We can take the flexible indirect module as the driving object. By changing driving parameters, an instantiated general module could be obtained. Then add optimization features which can be called the special module to the general module to obtain an optimized model. Subsequent optimization of structural static strength, fatigue strength, etc. can be used as a special module.

Take the frame of civil aircraft as an example. A complete frame can be divided into four segments including the upper, the lower, the left, and the right. They all consists of a floating frame and some clips. The designing steps of the floating frame can be divided into about 10 steps as shown in table 1.

| Designing steps | Surfaces used | Geometric parameters | Numerical parameters |
|-----------------|--------------|----------------------|---------------------|
| Thick surface   | Fuselage profile, Frame plane, Level plane, Upper fuselage profile | Fuselage profile, Frame plane, Level plane | Frame plane offset (X₁, X₂), Thick surface offset (A₁, A₂) |
| Split 1         | Upper fuselage profile, Frame plane, Stringer sweeping surface 1, Stringer sweeping surface 2, Upper frame segmented surface (left) | Upper fuselage profile, Frame plane, Stringer sweeping surface 1, Stringer sweeping surface 2 | Frame boundary surface (left) offset B₁ |
| Split 2         | Upper frame segmented surface (right), Fuselage vertical plane | Fuselage vertical centerline plane | Frame boundary surface (right) offset B₂ |
Fuselage profile denoted by $fpr$, frame plane denoted by $fpl$ and stringer sweeping surface denoted by $sss$ are selectable geometric parameters. Different parameters can be chosen to design frames at different frame positions, as shown in figure 1 below. The level plane and fuselage vertical centerline plane in table 1 are fixed in a certain type of civil aircraft.

![](image)

**Figure 1.** Frames at different frame positions.

$$F_{puf} = f(fpr, fpl, sss_1, sss_2, X_1, X_2, A_1, A_2, B_1, B_2, X_3, X_4, H_1, H_2, D, R)$$  \(\text{(1)}\)

$$F_{puf} = f(G_{puf}, N_{puf})$$  \(\text{(2)}\)

$F_{puf}$ represents all the parameters for designing the upper frame. $G_{puf}$ represents the geometric parameters, and $N_{puf}$ represents the numerical parameters.

Denote these parameters such as $upper$ $frame$ $segmented$ $surface$ $(left)$, $B_1$, $upper$ $frame$ $segmented$ $surface$ $(right)$, $B_2$, $X_1$, $X_4$, $H_1$, $H_2$, $frame$ $plane$, $D$ and $R$ as $I_{puf}$. $I_{puf}$ represents interface parameters on the upper frame module. We can make the upper frame cooperate with other modules by changing the parameter $I_{puf}$.

$$I_{puf} = I_{puf-left} I_{puf-right} U I_{puf-1} U I_{puf-2} U$$  \(\text{(3)}\)

| Split 3 | Frame plane | Frame plane | Frame plane offset $X_1$ |
|--------|-------------|-------------|--------------------------|
| Split 4 | Frame plane | Frame plane | Frame plane offset $X_4$ |
| Split 5 | Upper fuselage profile | Upper fuselage profile | Upper fuselage profile offset $H_1$ |
| Split 6 | Frame plane, Upper fuselage profile | Upper fuselage profile | Upper fuselage profile offset $H_2$ |
| Shell 1 | Frame plane | Frame plane | Frame web thickness $D$ |
| Shell 2 | Frame plane | Frame plane | Frame web thickness $D$ |
| Edge Fillet | R | | |

Centerline plane

| Split 3 | Frame plane | Frame plane |
|--------|-------------|-------------|
| Split 4 | Frame plane | Frame plane |
| Split 5 | Upper fuselage profile | Upper fuselage profile |
| Split 6 | Frame plane, Upper fuselage profile | Upper fuselage profile |
| Shell 1 | Frame plane | Frame plane |
| Shell 2 | Frame plane | Frame plane |
| Edge Fillet | R | |
\( I_{\text{pup-Lf}} \) represents interface parameters with the left frame. \( I_{\text{pup-Rf}} \) represents interface parameters with the right frame. \( I_{\text{pup-s}} \) represents interface parameters with the aircraft skin. \( I_{\text{pup-x}} \) represents interface parameters with other structures. As shown in Table 2.

**Table 2. Interface parameters.**

| Parameter type | Interface parameters                        |
|---------------|--------------------------------------------|
| \( I_{\text{pup-Lf}} \) | upper frame segmented surface (left) \( B_1 \) \( H_2 \) frame plane \( D \) |
| \( I_{\text{pup-Rf}} \) | upper frame segmented surface (right) \( B_2 \) \( H_2 \) frame plane \( D \) |
| \( I_{\text{pup-s}} \) | \( H_1 \)                                  |
| \( I_{\text{pup-x}} \) | \( X_3 \) \( X_4 \) \( H_2 \) frame plane |

For the parts and the assembly, we can denote the interface parameters as \( I_p \). The standardization of the interface is the prerequisite for realizing the variant design based on the instance of the modular product [4].

\[
I_p = f(I_{\text{pg}}, I_{\text{pn}})
\]

(4)

\( I_{\text{pg}} \) represents the geometric interface parameters, and \( I_{\text{pn}} \) represents the numerical interface parameters.

\[
M_p = F_p - I_p
\]

(5)

\( M_p \) represents the modeling parameters independent of the interface parameters.

\[
F_p = \begin{bmatrix} G_p & N_p \end{bmatrix} = \begin{bmatrix} M_p & I_p \end{bmatrix}
\]

(6)

\( F_p \) represents the parameters that may be used in the frame design process. \( G_p \) represents the geometric parameters, and \( N_p \) represents the numerical parameters.

Take civil aircraft for an example. Aircraft parts are slowly upgraded, but there are a lot of parts with the same or similar function and similar structure that need to be optimized.

By planning the product family of the parts, the flexible indirect module of the similar structure is divided into general module and special module. The module library creation process of the frame is given as follows.

Firstly, structurally analyze the product on the basis of the design ideas of product parts and functional analysis. The frame’s main structure may consist of the upper, the lower, the left, and the right frame, which all consists of a floating frame and some clips.

Then, extract the driving parameters as shown in table 1. They include the geometric parameters and the numerical parameters.

Furthermore, create the flexible indirect model. Create a parametric model of the frame based on the driving parameters.

Finally, design the adaptable module interfaces. Make adaptable design for the interfaces of the other modules as well as the frame module, in order to replace the modules for product upgrading and maintenance.

\( U_{pi} \) represents the useful parameters corresponding to a module instance of the flexible indirect module. It contains not only structural design parameters, but also engineering constraints, such as load, stress and strain, and characteristic parameters, such as material.

\[
F_p = \begin{bmatrix} U_{p1} U_{p2} U_{p3} \end{bmatrix} U_{pi} \begin{bmatrix} U_{p1} & U_{p2} & U_{p3} \end{bmatrix}, i = 1, 2, \ldots, m
\]

(7)

In order to make the flexible indirect model more versatile in the instantiation process, it is allowed to have redundant features and redundant parameters in the modeling process. So some parameters
denoted by $F_p$ may be redundant in some frames. But it makes the parameters in each $U_{pi}$ as uniform as possible and reduce differentiation. When creating a part sketch, the sketch is allowed to contain more information and skeleton structure than what is actually required by any single instanced module. The unified design of multiple similar parts makes a common module applicable to multiple different parts. We call this sketch as flexible sketch. Take the frame as an example. Although most frames can be divided into four parts, some frames will be different with others. Because they will be interrupted by structures such as fuselage door surround structures. But they can be designed with one sketch which contains the information required for all frames, as shown in figure 2. The difference of frames can be achieved by adjusting driving parameters or adding special modules on the adaptable design platform [5], as shown in figure 3.

![Comparison of the frame and its complete sketch.](image1)

**Figure 2.** Comparison of the frame and its complete sketch.

![The design process of the part on indirect modular adaptable design platform.](image2)

**Figure 3.** The design process of the part on indirect modular adaptable design platform.
Just as the left frame and the upper frame can be matched by parameter \( I_{pf} \), the frame can be matched with other structures by \( I_p \). When we design the upper frame, the numerical parameters can be discretized, and the geometric parameters can be the only one or discretized. So are other products. For the parameterized product family, parameter matrix is shown below, denoted by \( A_{n \times n} \).

\[
A_{n \times n} = \begin{bmatrix} F_{pf1} & F_{pf2} & L & F_{pf3} & L & F_{pf4} & \cdots & F_{pfn} & L & F_{pfn} \end{bmatrix} = \begin{bmatrix} Q_i & L & Q_i & L & Q_i & \cdots & Q_i & L & Q_i \end{bmatrix}^T
\] (8)

\[
F_{pfj} = \begin{bmatrix} f_{pr} & f_{pl} & s_{ss1j} & s_{ss2j} & X_{1j} & X_{2j} & A_{1j} & A_{2j} & B_{1j} & B_{2j} & X_{3j} & X_{4j} & H_{3j} & H_{2j} & D_i & R_j \end{bmatrix}
\]

corresponds to the parameters of the upper frame. \( i = 1, 2, \ldots, n \). \( n \) represents the number of the frame that can be modularly designed. \( Q_i \) represents a set of discretized values of a driving parameter.

Just as we can establish the upper frame model with \( F_{pfj} \). The module instance \( M_{qf} \) is uniquely determined by \( F_{pfj} \cdot M_{qf} = f(F_{pfj}) \). The whole product is composed of all the modules.

\[
M_{fi} = \begin{bmatrix} M_{qf}, M_{qf}, M_{qf}, M_{qf} \end{bmatrix}, \quad i = 1, 2, \ldots, n
\] (9)

where, \( M_{fi}, M_{qf}, M_{qf}, M_{qf} \) and \( M_{qf} \) represent the module instances of the frame module, the upper frame module, the left frame module, the right frame module and the low frame module.

The discretized values \( Q_i (i = 1, 2, \ldots, m) \) can be inputted into the platform while checking in the module. Then the parameterized family modules are created in the platform.

4. Output the typical module

Indirect modular design not only expands the applicable field of modular design, but also accumulates a large number of typical structures that can be modularized during the design process. Based on this, rapid module construction can be achieved, and more intuitive product types can be provided for the customers. The reference makes the product's response to customer needs faster and more accurate, and enables direct communication between the design and customer needs.

5. Conclusions

The indirect modular technology is a design method to build product parameterized family modules based on the traditional modular design and the generalized modular design. The construction of indirect module provides the approach to modular design for products without obvious serialization and hierarchical characteristics. The design of new products can be quickly realized by reconfiguring, upgrading general modules and replacing special modules on the modular adaptable design platform. This paper tells an example of the frame in civil aircraft design to describe the idea of indirect modular design.

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