A Review of The Development of Civil Aircraft Family

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Abstract. The development of product family has become a major trend in industrial product research and development, which can meet the needs of market segments, shorten research and development time, reduce research and development costs, and quickly increase market share. The development of civil aircraft family is one of the important characteristics of modern civil aircraft design, which can bring significant economic benefits for aircraft life cycle. In order to meet the needs of the market and realize cost reduction and efficiency increase, the development of civil aircraft family has become the main direction of the development of modern civil aircraft, which has attracted widespread attention, and the major aircraft manufacturers have formed their own series of civil aircraft. Focusing on the development of civil aircraft family, this paper reviews the development of product family, the design of civil aircraft family and the development status of typical civil aircraft family in the field of civil aircraft. Then the challenges and future research directions of civil aircraft family are summarized and discussed.

1. Introduction

Serialization is a standardized form to optimize the structure and function of a certain product system. Product family refers to a series of products that are interrelated or similar among features, components, modules or subsystems. Based on the product platform, the product family strategy studies the development law of the same kind of products, scientifically arranges and plans the main parameters, types, dimensions and basic structure of the products through detailed technical and economic comparison, so as to coordinate the relationship between similar products and supporting products. Nowadays, the product serialization development strategy has been successfully applied in the industries of electronics, software, automobile, household appliances, etc. At the same time, it also has gradually been applied to the design and development of complex products such as aircraft, ships, satellites, etc. [1-3] In order to meet the diversified and personalized needs of civil aircraft customers, in the civil aircraft design, large-scale aviation manufacturers have developed basic, improved and derivative civil aircraft to form the civil aircraft family. The serialization of aircraft has commonality, which can reduce the cost of development and operation and improve the residual value of aircraft. Nowadays, the development of civil aircraft family has been one of the important characteristics of modern civil aircraft design, which can bring significant economic benefits for the whole life cycle of aircraft.

This paper provides a review of the development of civil aircraft family. Next, it introduces some contents and viewpoints of product serialization development. Then, combined with the literature, this paper summarizes the design of civil aircraft family and introduces the typical series of civil aircraft, providing reference for the development of Chinese civil aircraft family. Finally, the future research
direction and main challenges are proposed.

2. Development of product family
In the face of market flexibility and uncertainty, a single product will no longer adapt to market changes. For the development of product family, many researchers have conducted research. Meyer et al. [4] put forward two views on the product family. The simpler one is that a single product stream generated by a company is an evolving product series; the other is to regard a product family as a group of products derived from the same platform, but with specific characteristics to meet the diversity of customer needs. Erens et al. [5] defined a product family as a product with the same internal interface, that is, the interface between product components, for all variants in each family. In a product family, each product is referred to as a product variant or instance. In the face of a specific market segment, each product variant is developed to meet a specific customer demand subset of the segment.

Agard and De Lit et al. [6, 7] explained the product family from the perspectives of marketing and engineering manufacturing. From a marketing perspective, the functional structure of a product family shows a company's product line or product portfolio, and therefore has various functional characteristics for different customer groups. From the perspective of engineering manufacturing, the product families are characterized by different design parameters and part of the same components and assembly structure, highlighting product diversity and also reflecting the manufacturability of different design schemes in the same product family.

3. Civil aircraft family design
In the field of civil aircraft, seriation development has become the general trend. In order to develop product family reasonably, it is necessary to weigh the requirements of generality and diversity in series products, which includes the following two aspects of research content: the first is to study how to determine the architecture of product family; the second is to study how to determine the parameters of each product in the product family [8].

3.1 Architecture design of civil aircraft family
The architecture design of product family is to divide the functional components based on the decomposition of product functional structure, and realize the diversity of products through the combination of different functional components. The architecture design of product family should not only divide the composition of functional components, but also identify the core components of the common platform. Then, it is necessary to determine the physical parameters of each product reasonably, so that the ratio of comprehensive performance and price of the whole product family is optimal.

The tasks of serialized configuration design and general layout of civil aircraft can be decomposed into various systems of civil aircraft according to the function-structure analysis method, such as divided into fuselage, power system, flight control system, hydraulic system, fuel system, avionics system, etc. Each subsystem can be further divided into smaller subsystems (or components). According to the design requirements of each model in the series, determine the component composition; determine the components that make up the common platform; separate the special components. This work mainly belongs to qualitative analysis and design, and the final design result depends on the experience, intention and creative thinking of the designer. There are many aircraft family architecture design cases that can be referred to, such as the twin-fuselage configuration of small regional airliner family [9], Dornier’s use of internal and external wing configurations for the 75-seat and 100-seat regional jets [10], and blended-wing-body layout aircraft family of different tasks and different body divisions [11] and some heuristic rules to carry out the configuration design and overall layout of the civil aircraft family.
3.2 Parameter design of civil aircraft family

After the configuration design, general layout and common platform of the aircraft family are determined, the next step is to determine the parameters of each aircraft type, that is, to determine the parameters of the common platform and special subsystems. The parameter design of aircraft family can be regarded as a multi-objective optimization problem. Configuration design is to determine the combination of components or subsystems, and parameter design is to optimize the parameters of each subsystem under a given combination of subsystems.

The research on the parametric design method of aircraft family has attracted the attention of many scholars. Willcox et al. studied the shape design of Blended-Wing-Body aircraft family by using the simultaneous optimization method [12]. Allison et al. applied a decomposition-based method to determine the overall parameters of the aircraft family [13]. Thierry et al. regarded the aircraft family design as a multi-objective optimization problem, and studied the problems in the conceptual design stage of aircraft [14]. With the help of multidisciplinary design optimization (MDO) strategy, Yong Mingpei proposed a two-level optimization method based on agent model, and conducted a preliminary study on the overall parameters, aerodynamic shape, structural parameters and aerodynamic/structural integrated design of aircraft family [8]. The adoption of the common platform can effectively reduce the R&D (research and development) cost, but also leads to the performance degradation of one or several models. There is an implicit assumption in the product family design method: the more components or subsystems contained in the common platform, the more beneficial it is to reduce the life cycle cost. However, some studies have found that the more complex the platform, the higher the cost [15]. Quantitative analysis of the impact of aircraft serialization R&D strategy on the life cycle cost of aircraft is to analyze the impact of aircraft family on the cost, and find out the aircraft type combination with the lowest aircraft family cost. Fujita regarded such problems as the optimization of product portfolio under the maximization of product profit [16].

4. Typical civil aircraft family

In the field of aviation, aircraft families are usually composed of a benchmark aircraft and its derivatives or variants. However, an aircraft family is not limited to a reference aircraft and its derivative aircraft, it can also include multiple aircraft with different missions but still sharing a few key parts or systems [17]. Nowadays, mainstream aircraft manufacturers in the world have basically formed a number of product families covering the entire civil aircraft market, and have achieved model diversification in the same series of aircraft. For example, Boeing and Airbus have adopted mature aircraft series design concepts, and Bombardier and Embraer also have their own aircraft family in the regional airliner field. The following will mainly introduce the typical civil aircraft families in the global aviation industry.

4.1 Boeing aircraft family

Boeing is the world’s largest aircraft manufacturer, with B737 series, B747 series and other famous aircraft series, among which B737 series aircraft is the most successful series of Boeing products. It can be divided into traditional type and new generation type, among which the basic type is B737-100 type. There are five traditional types: B737-100/200/300/400/500, while the new generation includes five types of B737-600/700/800/900/MAX. The development of B737 series aircrafts is shown in Figure 1 below. The new generation B737 series aircrafts have the same parts and ground support equipment as the traditional type aircraft. In addition, most of the mechanical parts and ground support equipment of the five models of the new generation B737 are the same, which can save airlines a certain degree of operating costs [18]. At the same time, Boeing also plans to share technical resources from B787 to the B737 successor models, using the same cockpit, wings and engines, but with different fuselage widths [19].
4.2 Airbus aircraft family
Airbus’s four aircraft series include: single-aisle A320 series aircraft; wide-body A300/A310 series aircraft; long-range A330/340 series aircraft; and A380 double-decker super large passenger aircraft. Like B737 series aircraft, the single-aisle A320 series aircraft is also one of the most sold civil aircraft in the world. It has four aircraft types, namely A318, A319, A320, and A321. These four models have the same cockpit design and operating procedures, which can reduce pilot training and cockpit maintenance costs, thereby increasing operational flexibility [20]. The A320 series aircraft is shown in Figure 2 below.

![Figure 2. A320 aircraft family](image)

4.3 Bombardier aircraft family
Regional airliner refers to the aircraft with less than 100 seats and a range of 200-400km [21]. Aircraft manufacturers usually choose the appropriate seat class aircraft model as the basic model, and gradually develop a series of branch line series to meet the requirements of different seat levels and different purposes by lengthening or shortening the fuselage [22]. The CRJ series are civilian regional jet aircraft developed by Bombardier Aerospace Group, of which CRJ-200 is the current standard production model. According to the requirements, CRJ-100/200 series provides basic type, extended range type and long-range type for users to choose according to the difference of total take-off weight and voyage [23]. Based on the CRJ-200, the CRJ-700 is equipped with leading edge slats and new fuselage structure, and more thrust engines are installed. CRJ-900 is an extended type of CRJ-700, as shown in Figure 3 below.

![Figure 3. CRJ series aircraft](image)
5. Summary and prospect

This paper reviews the development of product family and the design of civil aircraft serialization. Civil aircraft family develops from basic type improvement to common platform design, which can bring considerable economic benefits to aviation manufacturers and operators and become the development direction of civil aircraft in the future. Since the development of China's civil aircraft is still in the initial stage, a serialized civil aircraft has not yet been formed, and there are still many challenges and problems in the serialized design of civil aircraft. Therefore, this article proposes the following research directions for the Chinese civil aircraft family:

1. Civil aircraft design emphasizes safety and economy. How to weight the relationship between the two needs to study the cost / performance of civil aircraft family. By evaluating the cost / performance index of civil aircraft family, the parametric design of aircraft family is optimized, and the economic benefits of civil aircraft family are quantified.

2. The aircraft design strategy based on the common platform is the future development trend. The influence of the complexity of the common platform on the design of aircraft family is studied, so as to introduce the research on the commonality design of aircraft.

3. Nowadays, the world civil aircraft market is mainly monopolized by Boeing and Airbus. If Chinese civil aircraft want to compete with it, it is necessary to study the uncertainty and flexibility of the market and find a breakthrough to form its own competitive advantage. Meantime, it also is necessary to make risk prediction and evaluation about the future market of series aircraft to deal with the complex market environment.

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