Research on the Design Service Goal of Civil Aircraft for Business Operation

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Abstract. In the design process of civil aircraft, its design service goal (DSG) is defined by the flight cycles, flight hours and calendar years. Civil aircraft for business operation are usually business jets, and do not follow fixed routes. Due to their specific operation mode, their daily utilization rate is significantly lower than that of conventional passenger civil aircraft. By analyzing the operation data of business jets that have been put into operation in the market, then calculate the design and service goals, and takes a large business jet as an example. According to the calculation results, different with the flight cycles in the commercial aircraft DSG, which is mainly affected by short range flight, the flight hours of the business jet may also be mainly affected by short range flight.

Keywords: aircraft, business jet, design service goal, operation data.

1 Introduction

The design service goal indicators of civil aircraft cover three dimensions: flight cycles, flight hours and calendar years. These indicators are not only directly related to the structural design of the aircraft, but also profoundly affect the economy of the overall operation of the aircraft. These indicators are usually expressed by setting the design service objectives (Design Service Goal, DSG) in the early stage of aircraft design. In the minimum design service goal time, the aircraft in the most unfavorable use environment, this index is one of the important indicators of aircraft structural fatigue design [1].

In the early research, for the design service goal focus on the comparison of competing model parameters, in recent years, with the rapid development of the civil market and demand change, the research method to market demand oriented, combined with retired years and the actual situation of the typical route, to develop the design of civil aircraft service target [2]. Zhang Fuze analyzed the internal relationship between fatigue life and calendar life [3]. Xu Jiwei analyzed the process and method of structural damage tolerance assessment [4]. Bi Yaping analyzed corrosion and fatigue life prediction of aircraft typical lap structures, and discussed the life envelope of different service areas and different flight intensities [5]. Miao Chenchen presented an engine

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service life prediction method based on mathematical statistics [6]. NK Chaika studied the planning and cost management of the aircraft life cycle, taking into account the interaction model of the various actors in the aircraft life cycle [7]. But when discussing the design service goal, it still needs to fully combine key elements such as flight cycles, length, and consider the flight cycles and the flight length characteristic [8][9] in a specific market.

The design service goal reflects the economy of the aircraft. Z Aka describes a methodology based on LCC (life cycle cost) to economically evaluate replacement strategies for aging aircraft from the perspective of an airline [10]. When the design service time is exceeded, the operating cost of the aircraft increases, and when the economic gap between the aging aircraft and the new aircraft is too large, the economic life is reached. It can continue to fly through supplementary analysis, evaluation and local changes. Lilley, B studied the life extension of composite aircraft structures [11]. From the true life of Boeing aircraft, many have exceeded the original minimum service target [12]. Therefore, it is not appropriate to blindly pursue too high design and service goals. If a design service goal is set that exceeds the market expectations, it will pay an additional price in terms of weight and cost.

Civil aircraft used for business operation are usually business jets. The main differences between business jets and commercial aircraft are the service object, the comfort of the cabin and the flexibility of the flight mission. For the service object, in addition to carrying special passengers, the purpose of business jets includes such as medical emergency and emergency rescue in case of disaster. For the comfort of the cabin, business jets offer luxurious cabin interior and plenty of in-flight entertainment, which means high maintenance and operating costs. For the flight mission, time and route of commercial aircraft are often fixed arrangements planned by the airline, and there are corresponding requirements for the take-off and landing airports, which are restricted by procedures to a certain extent, while the take-off time and flight route of business jets are tailored to the needs of passengers and do not follow the fixed route arrangement. Therefore, when defining DSG, it is necessary to consider that the daily utilization rate of business jets is generally lower than that of civil aviation, and the range of flight coverage is wide. This paper is mainly based on the statistical data of the operation market of air jet business jet, with the goal of covering the vast majority of customers, and discusses the ideas and methods of determining the service target of business jet design.

2 Service Year

In determining the design service goal, it is necessary to determine the expected flight calendar year of the aircraft, which is usually based on the statistics of the retirement year of the aircraft.

According to domestic research [8], the service life of aircraft may be 1.5 to 2 times of the design service goal, and old aircraft will continue to be used on the basis of meeting the safety requirements after reaching the design service goal. According to the distribution of the retirement time of the business jets, most of the business jets are retired within 45 years. Therefore, the design target life of the business jet can be set at 30 years. Retired service year of the business jet is shown in Figure 1.

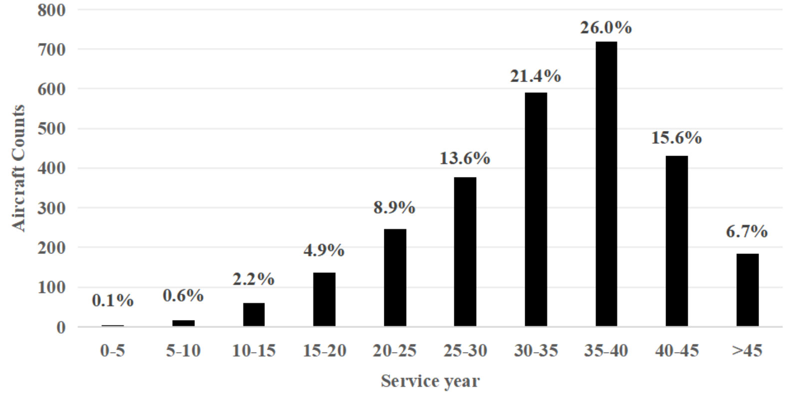

Fig. 1. Retired service year of the business jet.

3 Flight Cycles and Flight Hours

After determining the calendar year of the DSG, the flight cycles and the flight length should be determined. In the operational scenario of civil aircraft, the flight hours usually can be divided into three categories: short range, medium range and long range. For the flight length, without considering factors such as route winds and route detours, it can be approximated that the flight time follows a linear relationship with the distance of the route, that is, the flight hour is used to represent the length of flight.

In relevant research [9], short range, medium range and long range flight hours are determined by empirical formulas. As for the flight hours of business jets, most of the business jets do not perform fixed routes, and there are no typical routes. This paper proposes a method based on the analysis of the customer operation data of the same type of business aircraft in operation, and formulates the short range, medium range and long range flight hours through the distribution rules.

When determining the DSG, it is first necessary to determine the competing aircraft, either by the target market or by the length of the aircraft. Based on the analysis of the existing flight hours of these competing aircraft, the flight hours distribution of the competing models can be obtained. In the case of target customers, the proportion of short, medium and long flight hours expected to operate can be determined by investigating the operation mode of target users, and short, medium and long flight hours can be determined according to this proportion. In the case of no target users, the proportion relationship can be determined through experience, such as the proportion of short flights is 20% and the proportion of medium flights is 70% for commercial flights. For the flight cycles, on the one hand, the operation data of the existing competing aircraft is analyzed according to the currently determined short, medium and long flight hours, and the expected daily utilization rate is determined by weighted average, and the flight cycles is calculated based on the daily utilization rate. On the other hand, the fitting relationship between the flight hours and flight cycles of the competing aircraft is established, such as logarithmic fitting. The relationship between flight hours and flight cycles in existing operational data is analyzed to determine the expected flight cycles. Taking a certain type of business jet as an example, the distribution of operation data of the same type of business jet is shown in the figure. Overall, the flight hours are right-biased distributed, which can be approximated to follow a log-normal distribution, shown in Figure 2.

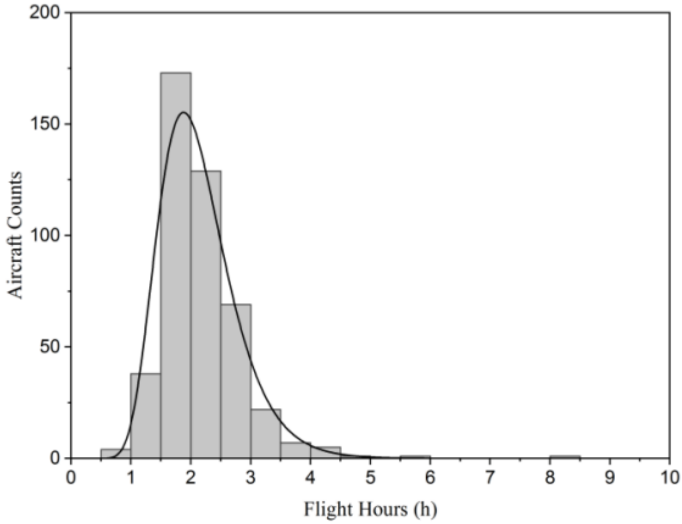

Fig. 2. Flight hours distribution of business jets.

In the aircraft development, the expected proportion relationship of short range, medium range and long range can be formulated. The flight hours are calculated by weighted average through proportional relationship and existing operational data.

$$\mathrm{FH_{short}} = \frac{\sum_{i=1}^{N\times N_1} h_i}{N\times N_1} \tag{1}$$

$$\mathrm{FH_{medium}} = \frac{\sum_{i=N\times N_1+1}^{N\times (N_1+N_2)} h_i}{N\times N_2} \tag{2}$$

$$\mathrm{FH_{long}} = \frac{\sum_{i=N\times (N_1+N_2)+1}^{N} h_i}{N\times N_3} \tag{3}$$

$$N_1 + N_2 + N_3 = 1 \tag{4}$$

In the formula (1 to 4), N1, N2 and N3 indicate the proportions of short range, medium range and long range, respectively. N means the number of operating data of the same type of business jet, Hi means the flight hours. For a large business jet, assuming that the market expected short range is 20%, medium range is 70% and long range is 10%, the market expected flight hours can be obtained as shown in the table 1.

Table 1. Flight hours of business jet.

	short range	medium range	long range
flight hours (h)	1.41	2.15	3.54

In its early years, Boeing counted flight routes and obtained the fitting relationship between flight hours and flight cycles to determine the minimum DSG [13]. Boeing's early statistics of aircraft relationships may not be applicable to business jets. Taking a large business jet as an example, the average annual flight hours and annual average flight times of the same level were fitted to analyze the characteristics of customers. Statistical analysis of the same business aircraft with more than 50 cumulative flights, and the average annual flight hours and average annual flight cycles comply with the relationship as shown in Figure 3.

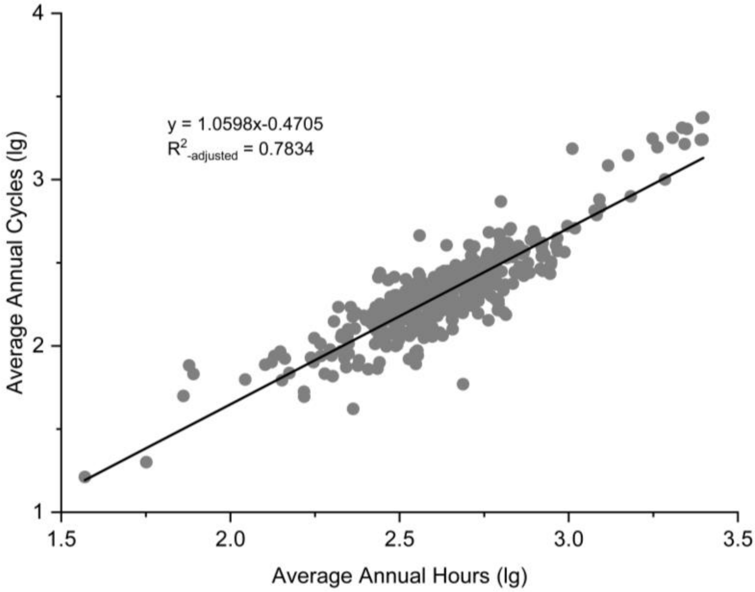

Fig. 3. The relationship between flight cycles and flight hours.

According to the statistical results, the annual average flight hours and annual average flight cycles of business jets of the same level meet:

$$FC_{AVA}=10^{1.0598\,\lg FH_{AVA}-0.4705} \quad (5)$$

In the formula (5), FHAVA means the average annual flight hours, FCAVA means the annual average flight cycles.

By analyzing the average flight hours and daily utilization rate of business jets of the same class, it can be found that the flight hours of business jets are mostly concentrated in 1-3 hours. For business jets with similar flight hours, their daily utilization span is large, which may be due to the operation mode of business jets. Business jets mainly serve private and corporate purposes and not aim for high daily utilization rates. The relationship between daily utilization and flight hours is shown in Figure 4.

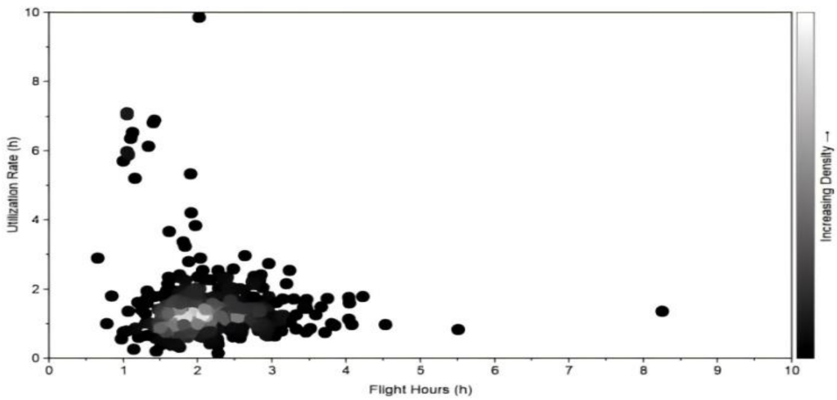

Fig. 4. The relationship between daily utilization and flight hours.

According to the predicted short range, medium range and long range flight hours, the expected daily utilization rate can be determined by the flight cycles corresponding to the similar flight hours in the operation data, or a certain proportion selected according to the coverage of the market target, and then the corresponding flight cycles and flight hours can be calculated according to the following formula.

$$FC_{AVA} = \frac{D}{FH} \times 365 \tag{6}$$

$$FC_{AVA} = FH_{AVA} \times h \tag{7}$$

In the formula (6 to 7), D means daily utilization and FH means flight hours.

In this paper, the daily utilization rate of the short range, medium range and long range flight hours of business jet is calculated respectively according to the inverse distance weighting method.

$$d_i = \sqrt{(FH - h_i)^2} \tag{8}$$

$$w_i = \frac{1/{d_i}^2}{\sum_1^n 1/{d_i}^2} \tag{9}$$

$$D = \sum_{i=1}^{i=n} w_i \times D_i \tag{10}$$

In the formula (8 to 10), d_i means distance, w_i means the weight. According to the above definitions of short range, medium range and long range, the corresponding 30 years flight cycles and flight hours are calculated as shown in the table 2.

Table 2. DSG of a certain type of business jet.

	short range	medium range	long range
flight hours (h)	1.41	2.15	3.54
Daily utilization rate (h)	3.75	1.28	1.752
30 years of flight cycles	29122	6519	3217
30 years of flight hours	41062	14016	11388

According to the relationship between the annual average flight hours and the annual average flight cycles of the same class business jets, the DSG can be conservatively defined as 40,000 flight hours / 20,000 flight cycles / 30 calendar years or 55,000 flight hours / 30,000 flight cycles / 30 calendar years.

According to relevant research [13], for commercial aircraft, the flight cycles are mainly affected by short range, and the flight hours are mainly affected by long range. However, for business jets, the situation may be different. From the calculation results, it can be seen that the medium range and long range of a certain type of business aircraft do not constitute stricter restrictions, while the short range constitutes stricter restrictions. Therefore, in the definition of flight cycles and flight hours, business aircraft may be different from commercial aircraft, and the flight cycles and flight hours of business aircraft are mainly affected by the short range.

4 Conclusion

Based on the analysis of business jet market operation data, this paper puts forward the definition method of business jet DSG combined with market operation data, and takes large business jet as an example. This paper provide reference for the formulation of design service goal, structural strength, and maintainability indicators for other business jets in the future. For aircraft structures and systems, the respective life can be determined by referring to the aircraft DSG, usually with the exception of life-limited components, to try to achieve the same life as the aircraft, in order to reduce maintenance costs. For other complex mechanical systems, its economic life indicators can also be analyzed with reference to market data, giving priority to ensuring its performance within the expected life of the market and reducing unnecessary costs.

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