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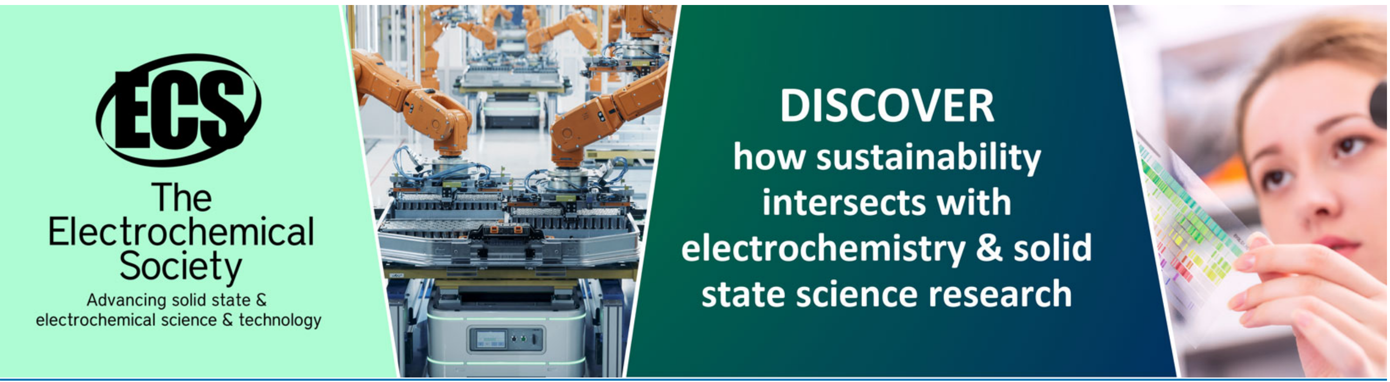

Research on mission characteristics-based evaluation model of flight test workload

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Abstract. As a product of modern industrial cutting-edge technology, a large civil aircraft needs to undergo rigorous flight test before entering the aviation market, which fully ensures the safety of aircraft and its system. This makes the aircraft meet the airworthiness standards and requirements. The flight test of civil aircraft is a complex system project, which the top-level planning throughout the flight test period has an important influence on progress control and flight test efficiency of a new type aircraft. The core content of the top-level plan is the evaluation of flight test workload with consideration of test aircraft quantity. This paper proposes a flight test workload analysis and evaluation model based on the types of test missions through the analysis of the characteristics of civil aircraft flight test mission, which provides a feasible method for quantitative evaluation of flight test workload.

1. Introduction

Aircraft flight test refers to the tests carried out by aircraft under real flight environment conditions. The purpose of flight test is to verify the results of design theories and ground tests, including identification of design indexes, airworthiness and performance. The aircraft design and ground tests are conducted under theoretical assumptions and non-comprehensive simulation conditions, the results require verification which the only means of verification will be flight tests [1].

The main objective of the civil aircraft flight test project is to obtain type certificate (TC) from the airworthiness authority, which allows the civil aircraft entering the aviation market and put into operation at an appropriate time to become a commercial airliner with market competitiveness. The type certificate (TC) is issued by the airworthiness authority to prove that the civil aviation products comply with the corresponding airworthiness regulations and environmental protection requirements [2]. The type certificate includes requirements towards aircraft type design, operation restrictions, data sheets, airworthiness and environmental protection, and other regulations or restrictions stipulated for civil aviation products [3].

In the long-term flight test project period, top-level planning is the top priority amongst all tasks. In the development process of modern advanced civil aircraft project, flight test planning and aircraft design are carried out in parallel. Among them, the workload evaluation of flight test is the upmost content of the top-level plan; it is closely related to the flight test total period, total cost, and test efficiency, which directly affects the flight test decision making. A reasonable workload evaluation of flight test can objectively reflect the progress of the flight test and is conductive to the overall control of aircraft type development project.

2. Flight test mission composition

In the flight test period of a new commercial aircraft, the flight test mission mainly includes research and development (R&D) flight tests (including the first flight and initial inspection), compliance flight tests, and operational flight tests. The workload evaluation of flight test is mainly focusing on these flight test tasks.

For different types of flight test mission, through analysing the mission structure and characteristics to conveniently construct a reasonable mission evaluation model.

According to the structure distribution of flight test mission at different stages of the flight hours, this paper would categories the flight test mission into three types, which are type A, type B, and type C.

All types of flight test mission usually consist of take-off phase, phase to enter suitable test airspace; phase to search for a suitable operable test point, test conduct effective phase, interval between effective tests, test time repetition, and landing phase. The composition of the effective test time and other required time is different for different types of mission.

Among the three types, flight test mission type A is the composition of multiple test points. During the entire flight test, both test points and effective test time are discrete.

In the decomposition of flight test mission, flight test mission can be divided into blocks, subjects and test points, according to the aircraft system functions and technical characteristics.

For example, Air Data System (ADS) Calibration subject in Aircraft Performance Test block [4]. Suppose that the R & D flight test of this subject needs to complete n_D test points, and the time required for each test point is $t_D\left(t_{D_1},t_{D_2},\cdots,t_{D_n}\right)$ min, with $n=n_D$. Similarly, assume that the compliance test of this subject needs to complete n_C test points, and the time required for each test point is $t_C\left(t_{C_1},t_{C_2},\cdots,t_{C_m}\right)$, with $m=n_C$. In one sortie, there is interval between each effective test point, which meant to readjust the attitude of the aircraft and finding the next suitable test point after completion of each test point.

Flight test mission type B has continuous effective test time in a flight mission. The whole mission process can be composed of take-off time, enter test airspace time, effective test time, exit test airspace time, and landing time. The effective time in type B mission usually lasts for a long flight time. Typical example is the FGCS /Auto Thrust Engagement /Disengagement subject in the Automatic Flight System Test block [5, 6]. R & D and compliance of this subject flight tests each need to complete a 100 flight test hours, and effective of this type of test begins right after taking off into the test airspace. This type of subject usually has long-term effective test time right after entering the test airspace, for example, in a 4-hour flight, the takeoff and landing and entering the test state (including the time to find the test airspace and adjust the aircraft status) takes about a hour. The effective test time lasts for 3 hours.

Type C flight test missions are the flight schedules which are not scheduled independently. but they may be combined with other similar types of flight test subjects, for example, the Passenger Oxygen System Test subjects in the Oxygen System Test block have no other requirements as long as the aircraft is in the air, it may be combine tasks with auto flight system test block or other similar blocks.

The flight test missions of civil aircraft are planned with block, subjects, and test points, which are decomposed level by level, thus forming a complete flight test workload evaluation system. An example is shown in the table below.

Table 1. Type example of flight test mission.

Block	Flight Test Subject	Test Classification	Type	Test Point
Aircraft Performance Test	Air Data System (ADS) Calibration	D/C	A	$n_D + n_C$
	Stall Speed	D/C	A	$n_D + n_C$
	Takeoff Performance	D/C	B	
	Abuse Takeoff	C	B	
	Drag Polar Curve	D	B	
	……			
Controlability & Stability Evaluation	Parameter Identification	D	A	Similar to n_D
	Stall characteristics and stall warning	C	A	Similar to n_C
	Control law adjustment	D	A	Similar to n_D
	……			
Automatic Flight Control System Test	FGCS/Auto Thrust Engagement /Disengagement	D/C	B	Similar to $n_D + n_C$
	Envelope Protection Function for Automatic Flight System	D/C	B	Similar to $n_D + n_C$
	……			
Oxygen System Test	Passenger Oxygen System Test	C	C	
Operation Test	Function and Reliable Test	D/C/O	B	
	……			

3. The basic structure model of workload analysis and evaluation

In a flight test system with mature management and technology, the ideal flight test mission workload estimation model of new aircraft should be establish based on clear logical structure, determined inputs, clear subjects and test points, in addition, a large flight test database consist of test time and limiting conditions of various test points for reference.

On this basis, the time structure of effective test time and non-test time in a single sortie can be obtained by statistical model based on abundant flight test data. The flight test efficiency and economic cost-benefit of a new aircraft type may be maximized in terms of workload, total flight time and total sorties, by using relatively transparent scientific mathematical model.

The flight test workload is the estimated result of comprehensive consideration of flight test subjects, flight test points, flight test sorties and other factors. A top-down analysis of test flight mission workload can be expressed by the total time used for a complete flight test period; this includes the time necessary for flight test subjects and test points, and other necessary time.

Let the time used for a single test point be T_{sin}, which includes the necessary test time T_{test} and non-test time T_{intest}.

with $$T_{sin} = T_{test} + T_{intest} \quad (1)$$

Let each flight sortie as T_{Fsin}, one mission sortie includes several test points, thus $T_{Fsin} = T_{sin_1} + T_{sin_2} + \ldots + T_{sin_i}$, where $i = 1,2,3,\ldots,n$, $n \in R$.

then $$T_{Fsin} = \sum_{i=1}^{n} T_{sin_i} = \sum_{i=1}^{n} (T_{test} + T_{intest})_i \quad (2)$$

In the actual flight test, the structure of non-test time on each sortie is different. T_{intest} can be divided into general non-test time $T_{Gintest}$, such as the time required for take-off and landing, and irregular non-test time $T_{Mintest}$,such as the time for adjusting aircraft status between test points. Therefore, in ideal conditions, the time structure of the test aircraft during a flight test mission can be expressed as:

$$T_{Fsin-new} = \sum_{i=1}^{n} T_{sin_i} = T_{Gintest} + \sum_{i=1}^{n} (T_{test} + T_{Mintest})_i \,,\quad i = 1,2,3,\ldots,n \,,\quad n \in R \quad (3)$$

The flight test mission time structure of the flight subjects Type A and Type B is shown in the figure below.

In the figure 1, the search time including the time to enter the test airspace, finding the appropriate test airspace & opportunity to conduct the test, and exiting the test airspace in single flight test.

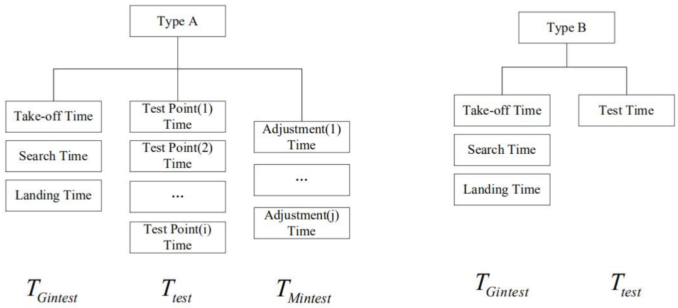

Figure 1. The time structure of Type A and Type B.

The total flight test workload of the new aircraft type can be expressed by the total flight time T_{TOT} of all flight sorties required to complete all flight test mission.

where $$T_{TOT} = T_{(Fsin-new)_1} + T_{(Fsin-new)_2} + \ldots + T_{(Fsin-new)_j} \,,\quad j = 1,2,3,\ldots,m \,,\quad m \in R \quad (4)$$

then $$T_{TOT} = \sum_{j=1}^{m} T_{(Fsin-new)_j} \quad (5)$$

In actual flight test process, the scheduled flight test mission may not be completed every time, because some test points may be invalid, therefore that particular test point needs to be repeated. In case of invalid test points, the flight test points or missions conducting retests shall be recorded as invalid sorties or invalid tests, refer as $T_{Fsin-ie}$.

For ease of estimation, when the number of flight test subjects and test points quite large, the probability of occurrence of $T_{Fsin-ie}$ can be expressed by coefficient τ according to the existing flight test experience and data,

where $$\tau = \frac{T_{Fsin-ie}}{T_{Fsin-ie} + T_{Fsin-new}} \quad (6)$$

then $$T_{TOT} = \sum_{j=1}^{m} (1+\tau) T_{(Fsin-new)_j} \quad (7)$$

Obviously, for flight test subject type A, we have

$$T_{TOT_A} = \sum_{j=1}^{m} (1+\tau) \left[T_{Gintest} + \sum_{i=1}^{n} (T_{test} + T_{Mintest})_i \right]_j \quad (8)$$

And for flight test subjects Type B, we have

$$T_{TOT_B} = (1+\tau)\sum_{j=1}^{m}\left[T_{Gintest} + \sum_{i=1}^{n}(T_{test})_i\right]_j \tag{9}$$

As for flight test subject type C, since the tests are not carried out individually, the flight time is added to type A and/or type B calculations.

In the development stage of a new aircraft type, there is a lack of corresponding input details in the initial stage of establishing flight test top-level planning. The input information is largely relying on the reference to the flight test data and experience of existing aircrafts. In the top-level planning stage uncertainty and lack of data, evaluation and estimation of flight test mission may be carried out though utilizing encrypted data from suppliers and previous experiences. With the development of the new aircraft, improvement of the flight test planning method and calculation of the mission workload when the test mission requirements and constraints become clearer, after which carried out iterations to bring the system closer to relative reasonable model and solution.

4. Conclusion

With the final goal of obtaining type certificate for civil aircraft, this paper proposes a hierarchical planning system with flight test blocks, subjects and test points. A quantitative workload evaluation model of flight test mission is established, to analyse the mission structural characteristics and time distribution in the process of flight test to detail, which provides a simple and operable method for a reasonable evaluation of flight workload.

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