A Method for Constructing Software and Hardware Comprehensive Reliability Test Profile of Y Model

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Abstract. In order to deal with the problem of software intensive equipment reliability evaluation test, this paper analyzes and compares the characteristics and shortcomings of current reliability evaluation test and software test, and puts forward the integrated reliability evaluation test technology of software and hardware. Through the design of software profile based on reliability comprehensive test and matching of software and hardware profile based on task profile, the test is carried out by using data automatic loading, and the test evaluation technology of fuzzy software and hardware fault classification is used to evaluate the test. Through the application test of a certain type of airborne equipment, it is shown that the reliability identification test technology of software and hardware integration can effectively expose the fault of software-intensive equipment, which is in line with the requirements of the current development of equipment and weapons, and has a good application prospect.

1.Introduction

Software-intensive equipment refers to the equipment system dominated by software in one or more aspects, such as the functional characteristics of equipment, development costs, development risks and development time, that is, the equipment system with software as the core [1]. In this kind of equipment, more and more functions are realized by software. The original algorithms and functions realized by hardware are gradually realized by software combined with hardware. Some functions have even been realized by pure software. Software plays an important role in this type of equipment, and has become its core and soul. Software defects lead to system failure. The rate is also increasing. At the present stage, the software-intensive equipment is tested and evaluated by means of reliability qualification test and software test separately. These equipment have passed reliability qualification test and software test according to the level of finalization in the development and finalization stage, and the problems are dealt with to zero. However, the use of the equipment delivered to the army still reveals no problems. Few reliability problems show that the current methods of reliability qualification test and software test are inadequate to expose the weak links of the reliability of weapon system. The single reliability test and software test can not expose the related faults between software and hardware, and the test results can not truly reflect the reliability level of software-intensive equipment. There is an urgent need to improve or propose new test methods for software-intensive equipment, test and evaluate them, so as to eliminate the hidden trouble in the equipment development stage as soon as possible.

In view of the characteristics and shortcomings of the current reliability qualification test and software test, this paper proposes a method of constructing the profile of the comprehensive reliability test of software and hardware based on Y model, introduces its implementation process, and verifies the application of this technology.

2.Related Work

Reliability qualification test and software test in reference are two very important tests in model development, and are important means to evaluate equipment quality. They have been carried out for many years in model engineering [2,3]. According to GJB 899A-2009 "Reliability testing for qualification and production acceptance", a set of mature solutions have been put forward from the design of test profile, the application of test stress to the performance test and fault criterion of the products in the test [4]. Through the synchronization of design temperature, humidity, vibration and electrical stress, four environmental stresses have been synchronized. When the equipment is checked, the design of synthetic test profile is mainly based on temperature, which combines electrical stress and vibration stress to form a comprehensive test profile. Documents [5,6] discussed how to determine the stress parameters of test profile from real environment and working profile, based on reference stress and using measured data, and mainly focused on the test of GJB899A-2009. Fine adjustment of adaptability is made for the test profile.

At present, the main purpose of software testing is to check whether the software meets the general requirements of system development or the tactical and technical indicators prescribed by the general requirements of software development, and to find, locate, correct and eliminate software defects through testing, which belongs to functional conformity testing and emphasizes quality conformity. However, software reliability testing with biased reliability evaluation is seldom used in engineering. One of the important reasons is that the applicability and operability of the test profile construction method is not high. The paper [7] explores the solutions for different applications, and the construction method for the software-hardware joint profile is seldom seen in the literature.

In the joint test of hardware and software, the reliability test with software test is discussed in reference [8], but the construction of comprehensive test profile is not involved. Document [9] considers that there are three kinds of failures for large-scale software and hardware systems consisting of hardware embedded with software: hardware failure, software failure and combined effect failure of software and hardware. It is stipulated that the stresses to be applied to reliability test of such systems include operating load and environmental stress (temperature, humidity, vibration). However, it is not clear how to formulate the test section, how to determine the working load, the applied time, the applied frequency and so on.

3.The software and hardware comprehensive test section construction technique of Y model

On the premise of not changing the current management and technical mode of reliability qualification test and software test, and aiming at informationized equipment, based on GJB 899A-2009, the integrated software and hardware reliability qualification test technology refines and improves the design of test scheme, and fully considers the operation profile of software. On the basis of the existing reliability qualification tests, the original test points are replaced by perfect software test profiles, and the system reliability qualification tests combined with hardware and software are implemented. The design of the test profiles and the requirements of the reliability qualification tests are in accordance with the user's use environment and conditions as close as possible, which can cope with transmission. The inadequacies of the overall reliability qualification test and the separate software third-party test/stereotyping test expose the system problems of software-hardware interaction that cannot be found [8], as shown in Figure 1. Following is an example of airborne equipment to introduce Y model software and hardware integrated profile construction technology.

3.1. Hardware Reliability Test Profile Design

3.1.1. Single Task Reliability Test Profile

Firstly, according to the design requirements of the equipment and its carrier aircraft and the combat mission profile, the task characteristic parameter diagram is drawn (see Figure 2(a)). Secondly, the data of each mission stage, altitude, Mach number and dynamic pressure are obtained from the equipment design performance specification and mission profile. The method provided by "B.3.4.2" and "B.3.5.2" in GJB899A-2009 is calculated or obtained. With the necessary data (temperature, temperature change rate, vibration stress, electrical stress, humidity, etc.) and the data provided by the task characteristic parameter diagram, the data needed for drawing the environmental profile are obtained: task stage, duration, height, Mach number, cabin temperature, temperature change rate, dynamic pressure q, probability spectral density W0, W1, dew. Point temperature, equipment status, etc., and draw the environmental profile (see Figure 2(b)). Finally, according to the principle stipulated in "B.3.5.2.3" in GJB899A-2009, the humidity, temperature change rate and vibration data in the environmental profile are processed, and the test profile data (mission stage, duration, temperature change) are obtained by processing (Chemicals, W0, equipment status and so on). Draw the test profile (as shown in Figure 2 (c)). The test profile should include temperature test profile and vibration test profile. The test profile should be divided into two cases: cold day and hot day. Electrical stress cycle and humidity stress can not be expressed on the section because of their simplicity.

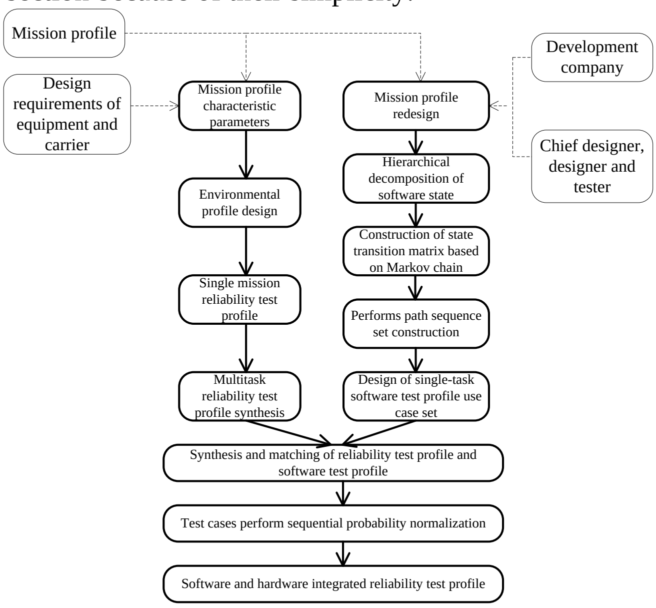
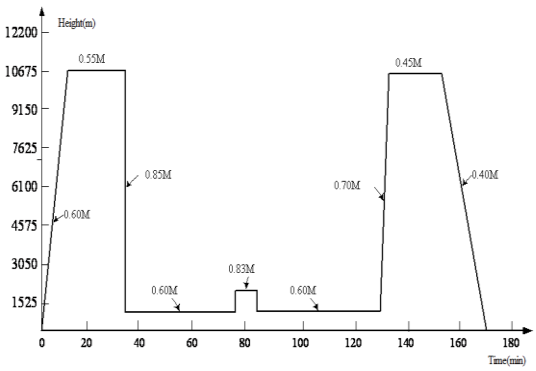
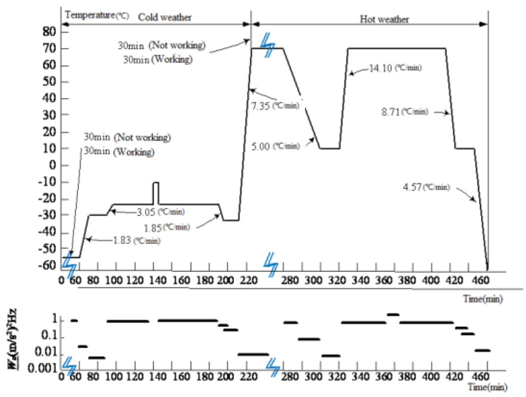


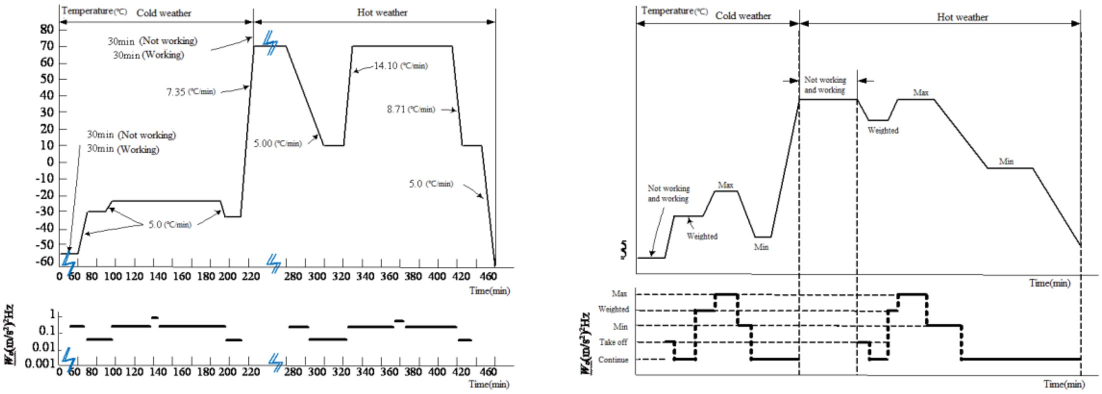
Figure 1. Y model software-hardware comprehensive reliability test profile construction technology



(a)Task profile-characteristic parameter map



(b) Environmental profile



(c)Test profile (d) Composite test profile structure

Figure 2. Structural charts of single-mission reliability test profiles and synthetic test profiles

3.1.2Multitask Reliability Test Profile Synthesis

The synthetic test profiles are mainly temperature test profiles and vibration test profiles. The time series of each vibration value in the vibration profiles is consistent with the temperature time series, and the principles of the two synthetic methods are basically the same. The temperature profile synthesis method of multitask reliability test profile is as follows:

Firstly, the relative frequency estimates of each task (i.e. the proportion of each task in the total task, expressed by weighting factor f) are listed. The total weighting factor of each task is 1.

Then, each steady-state temperature step level T and its duration t are listed according to each task profile, and the product of task weighting factor f and duration t is used as the weighted duration ft, as shown in Table 1.

Table 1. Temperature value table of each mission profile

Mission profile	weighting factor	Task stage	Temperature	Duration	Weighted duration
		A_{11}	T_{11}	t_{11}	f_1t_{11}
A_1	f_1	A_{12}	T_{12}	t_{12}	f_1t_{12}
		A_{13}	T_{13}	t_{13}	f_1t_{13}
		…	…	….	…
		A_{21}	T_{21}	T_{21}	f_2t_{11}
A_2	f_2	A_{22}	T_{22}	T_{22}	f_2t_{22}
		A_{23}	T_{23}	T_{23}	f_2t_{23}
		…	…	….	…
…	…	…	…	…	…
		A_{n1}	T_{n1}	t_{n1}	f_nt_{n1}
A_n	f_n	A_{n2}	T_{n2}	t_{n2}	f_nt_{n2}
		A_{n3}	T_{n3}	t_{n3}	f_nt_{n3}
		…	…	….	…

Thirdly, the same temperature values in Table 1 are merged and the weighted duration corresponding to merged temperature is accumulated to obtain the weighted duration. A two-column summary table of temperature values with only temperature values and total weighted duration.

Finally, the maximum temperature value T_{MAX}, minimum temperature value T_{MIN} and weighted temperature value T_{INT} in cold and hot days are determined. $T_{MAX}(T_{MIN})$ is a weighted synthesis of temperature values in the range of 5℃ of the highest (lowest) temperature value, whose duration is the sum of the total weighted duration corresponding to the weighted temperatures; T_{INT} is the weighted average of all remaining temperature values except T_{MAX} and T_{MIN} weighted temperature values (multiplying all remaining temperature values by pairs, respectively). The total weighted duration is divided by the sum of the corresponding total weighted duration, and the duration is the sum of the total weighted duration corresponding to the weighted temperature values.

Similar methods are used to determine the takeoff vibration values W_{OTO}, W_{OC}, W_{OMAX}, W_{OMIN} and W_{OINT} in cold and hot days, which have five vibration values and duration.

Finally, the temperature test profile is used as the main line to draw the multi-task synthetic test profile, as shown in Figure 2(d).

3.2. Software Test Profile Design

The key point of software profile design of hardware and software comprehensive test should be based on the actual use of users. The timing and frequency of operation execution are determined by the task profile. The task profile is expanded by using information, the system state and working mode are extracted, and the state transition matrix is constructed based on hierarchical Markov chain using model. The execution path sequence with execution probability assignment is formed. The input parameters are designed according to test case design methods such as equivalence class and boundary value. Finally, the test case set is formed and the software test profile is constructed.

3.2.1. Redesign of Task Profile

Generally speaking, the mission profile obtained by mission scenario modeling includes the information of mission stage, operation mode, operation function, success criteria, mission time, environmental stress and time under the environmental stress of the equipment. The establishment of software test profile needs to add relevant information of software operation on the basis of task profile, and communicate face to face with field testers, designers and user representatives according to user documents and general plans, so as to acquire the software system in each phase of task profile one by one. Information such as status, working mode, etc. is obtained from the extended design of task profile in Figure 3 to the information in Table 2.

Table 2. Task Profile Extended Information Table

Serial Number (A_{ij})	Phase Name	Time (min)	Switching state	system state (S_k)	Working Mode (W_l)
	Task Profile A_i - "High-Low-Low-High" Profile				
A_{i1}	Take off	1	Turn off	Shutdown	/
A_{i2}	Set out and climbing	15	Turn on	BIT & Ready	/
A_{i3}	Flat flight stage A	36.5	Turn on	Working	Air-to-Sea
A_{i4}	Set out and descend	7.5	Turn on	Working	Air-to-Sea
A_{i5}	Flat flight stage B	15	Turn on	Ready	/
A_{i6}	Fighting area activities	5	Turn on	Ready	/
A_{i7}	Flat flight stage C	15	Turn on	Ready	/
A_{i8}	Return and climbing	5	Turn on	Ready	/
A_{i9}	Flat flight stage D	42	Turn on	Working	Air-to-Air
A_{i10}	Return and descend	11	Turn on & off	Ready	/
		....			

3.2.2. Hierarchical Decomposition of Software State

In Table 2, the software working mode sets that may appear in acquiring the equipment full mission profile are classified and summarized, and the typical working mode is obtained. Then, according to the documents such as “General Plan” and “Operator's Manual”, each typical working mode is decomposed layer by layer, and the lower working mode supported by the equipment is decomposed.

Table 3. Typical air-to-air Working mode conversion relationships

Working mode	Convertible mode
VS	RWS、TWS
RWS	VS、STT、SAM
TWS	VS、STT
STT	VS、RWS、TWS、SAM

SAM	RWS、STT、TWS

Taking fire control radar as an example, the software working mode set in the complete mission profile includes four typical working modes: air-to-air, air-to-sea, air-to-ground and navigation. Four working modes are decomposed at the next level, such as air-to-air working mode further decomposed into velocity search mode (VS), search while ranging mode (RWS), scanning while tracking mode (TWS), single target tracking mode (STT), situational awareness mode (SAM) and so on, as shown in Table 3.

3.2.3. Building State Transfer Matrix Based on Markov Chain

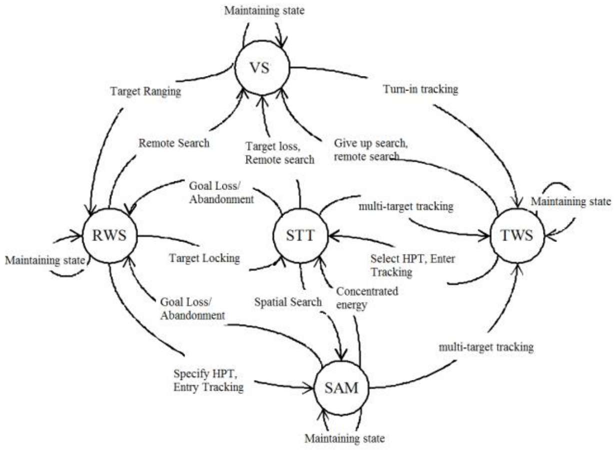


Figure 3. Task profile Ai - "High-Low-Low-High" profile

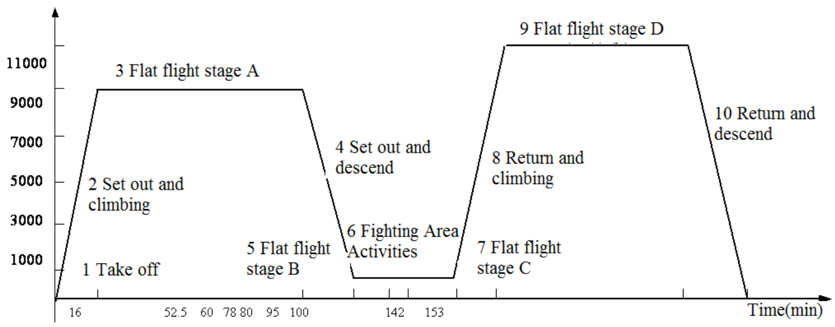


Figure 4. Air-to-air conversion diagram

Equipment software decides the switching of working modes according to operational tasks. There are certain constraints on the switching between modes: the same-level mode can be directly converted, and the switching between sub-modes is based on the switching between parent modes, while the switching of some modes must be guided by other modes if the switching between sub-modes is cross-parent mode. As shown in Table 3 and Figure 4, the hierarchical Markov chain usage model can be used to treat the same level of work mode as a whole and as a node in the Markov chain, encapsulating the transformation relationship of the same level to form a subset [10], so as to avoid the state space explosion problem of Markov chain. Markov chain is used to construct the transition probability matrix of the same level working mode. The transformation relationship between sub-modes in different modes at the same level is realized by the serial relationship between two sub-modes and the parent Markov chain.

Suppose that the state transition matrix A_k is a matrix of $n×n$, where $k \in \{1,\ldots,m\}$, m is the total number of working modes decomposed, n is the maximum number of working modes at the k level. Each $p_{kij} = P(X_{kt}=x_{kj}|X_{k(t-1)}=x_{ki})$ indicates the probability that the working mode x_{ki} will be transferred to the working mode x_{kj} [11] In the transfer matrix, if the two working modes x_{ki} and x_{kj} cannot be directly transformed, the state transition probability will be recorded. The rate p_{kij} is 0.

$$A_k=\left[p_{kij}\right]=\begin{bmatrix} p_{k11} & p_{k12} & \cdots & p_{k1n} \\ p_{k21} & p_{k22} & \cdots & p_{k2n} \\ \vdots & \vdots & \vdots & \vdots \\ p_{kn1} & p_{kn2} & \cdots & p_{knn} \end{bmatrix} \tag{1}$$

The transfer probability matrix AK satisfies the following two conditions:

$$p_{kij} \geq 0 \; for \; all \; i, \; j \in \{1, \ldots, n\} \tag{2}$$

$$\sum_{j=1}^{n} p_{kij} = 1 \; for \; all \; i, \; j \in \{1, \ldots, n\} \tag{3}$$

3.2.4. Construction of Execution Path Sequence Set and Design of Single Task Software Test Profile Case Set

According to (1)~(3), the sequence set $S=\{s_1, s_2, \ldots s_d\}$, each path s_d represents a complete use process of the software, which is equivalent to a basic test case. The path probability represents the user's usage habits. s_d has gone through several modes. Combined with the state transition matrix of Markov chain, the path probability p_{sd} corresponding to each path can be calculated.

Suppose that an execution path spans one parent A_k and two child state transition matrices $A_{k\text{-}1}$ and $A_{k\text{-}2}$:

$$s_d=x_{(k-1)j}\rightarrow x_{(k-1)(j-1)}\rightarrow x_{(k-1)(j-2)}\rightarrow x_{k1}\rightarrow x_{k2}\rightarrow x_{(k-2)i}\rightarrow x_{(k-2)(i-1)} \tag{4}$$

then,

$$p_{sd}=\prod A_{K-1}\cdot\prod A_K\cdot\prod A_{K-2}=\left(p_{(k-1)j(j-1)} * p_{(k-1)(j-1)(j-2)}\right) * \left(p_{k12}\right) * \left(p_{(k-2)(i-2)(i-1)}\right) \tag{5}$$

where,$\prod A_K$is the product of the state transition probability of the execution path in the state transition matrix A_k.

According to the method of test case design such as equivalence class, boundary value and so on, further use case design of Sd is carried out to form test profile, and the mapping table between task stage and Sd is established (as shown in Table 4).

Table 4. Mapping Table of Ai Task Stage and Sd in a Task Profile

Task phase	Execution path sequence
A_{i1}	s_3,s_{11},s_{13}
A_{i2}	s_1,s_4,s_7,s_{11}
A_{i3}	$s_2,s_3,s_5,s_6,s_9,s_{11}$
...	...

3.3Matching and Composition of Reliability Test Profile and Software Test Profile

Because hardware reliability is a function of time and the change of physical characteristics of devices with the accumulation of time, there is a phenomenon of bathtub curve, so hardware reliability mainly excites product failure by time accumulation of environmental stress, and the determinant factor of software reliability is software related to input data and internal state of program. The triggering of a fault depends on the path of the program, which is a function of the state space domain of the program path. In short, hardware reliability is a function of time, while software reliability is a function of space.

According to the characteristics of hardware reliability and software reliability, the time proportion of composite section of multitask reliability test profile is replaced by the probability proportion of execution of software execution path sequence from Aij phase of task, and the matching of "time" of reliability test profile with "space" of software test profile is realized. As shown in Figure 5, from the "2) Multitask Reliability Test Profile Synthesis" in section 2.1, the task source and duration ratio of the temperature step (-34.3℃) in the synthetic test profile are obtained (shown in the dotted line frame in the figure). Through the above "space-time matching", the sequence of execution paths and the probability of execution of the temperature step can be obtained (as shown in Table 5). The execution allocation between execution path sequences within a single Aij is determined by the psd of Formula (5). Finally, the normalized execution path sequence is processed to form a software-hardware integrated reliability identification test profile, as shown in Figure 6.

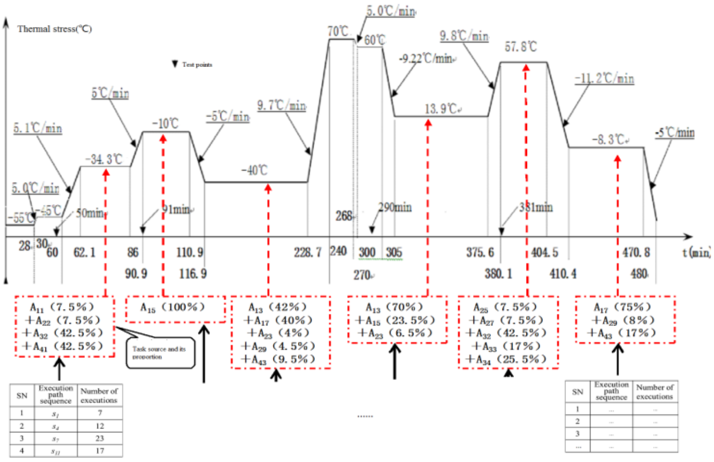


Figure 5. Software test Profile matching reliability qualification test profile

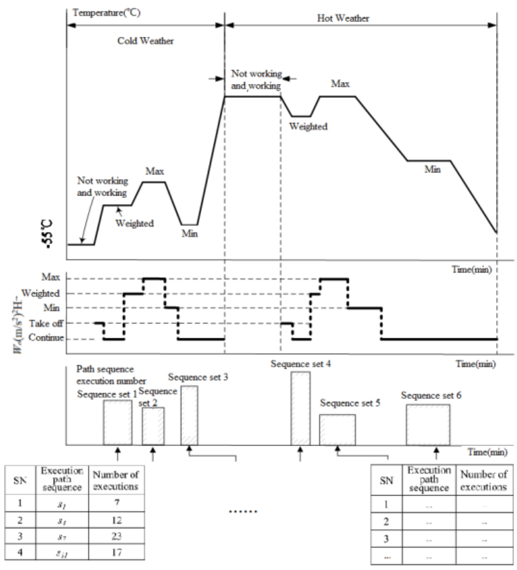


Figure 6. Software and hardware integrated reliability qualification test profile

TABLE 5. Task source of temperature step (-34.3℃) and Sd execution probability

Sources of mission phases	Task phase corresponding execution path sequence	Execution probability of execution path sequence
A_{11}	s_1,s_4,s_7,s_{11}	7.5%
A_{22}	s_1,s_4,s_7,s_{11}	7.5%
A_{33}	$s_2,s_3,s_5,s_6,s_9,s_{11}$	42.5%
A_{41}	s_1,s_4,s_7,s_{11}	42.5%

4.Application Verification

In the reliability qualification test of a certain airborne equipment, the "software and hardware integrated system reliability test technology" is validated. The total test time is 110h and 13.75 cycles. Six temperature steps in the comprehensive test section involve software operation and test (see figure 2). The number of basic use cases for software test profile design is 52, and the total number of normalized use case execution is 502. The problems not found in the original hardware reliability test and software test were exposed. The test found that there were 9 problems, including 2 problems of accompanying equipment, 6 problems of software and 1 related fault between software and hardware. The fault occurred many times in the field use of this equipment, and all of them were in "large-scale vibration and operation of large-angle pitch scanning power". Only under the specific combination of conditions, can the traditional reliability test be carried out separately. Because the assessment of software function state is not taken into account, the selection of test points is relatively simple, so it is difficult to find the system faults that this type of software and hardware interaction can expose. The third-party software testing/stereotyping testing is a comprehensive assessment of software functions. Most of them assume that the hardware is in an ideal state. Even though some illegal operations and illegal input data will be simulated, these simulations do not fully consider the software-hardware interaction in the actual use of equipment, and it is difficult to expose this type of failure.

It can be seen from that the Y-model software and hardware integrated profile construction technology replaces the original test points with the perfect software test profile. The design of the test profile and the requirements of the reliability test are consistent with the user's use environment and conditions as close as possible. It can fully expose the weak links of the equipment and cope with the traditional reliability. The insufficiency of test and independent software third-party test/finalization test can effectively assess the reliability of equipment.

5.Conclusion

Using Y model to construct the comprehensive reliability test profile of software and hardware, replacing the original test points with the perfect software test profile on the basis of the existing reliability test, supplementing and perfecting the existing reliability test methods and software test, GJB 899A-2009 is more effective in the application of information equipment, which is in line with the current situation. The requirement of equipment weapon development has a good application prospect.

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