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Study on Reliability Test of External Air-Launched Carrier Rocket

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Abstract

In this paper, the method of reliability test profile construction for air-launched spacecraft is analyzed, in order to effectively carry out air-launched spacecraft flight reliability test. The flight mission profile and environment profile of air-launched spacecraft are formed. Meanwhile, the method of temperature stress, vibration stress, electronic stress and humidity stress of external spacecraft under different mission profiles are calculated. Finally, this paper takes an airborne electronic product as an example, and a reliability test profile is designed by correction of the experimental section with measured data.

Keywords

Air Launch, Launch Vehicle, Reliability, Test Profile

1. Introduction

An air-launched carrier rocket is a carrier rocket that carries the carrier rocket to a certain height from the ground for launch. It is the product of the combination of modern aerospace and aviation industry, and it is an innovation of the traditional ground launch carrier rocket. It has the characteristics of being "mobile, flexible, high efficiency and cheap" and is basically not affected by the weather or the launch site [1]. In case of bad weather, the carrier can fly away from the area to avoid it and has the ability to respond rapidly. These advantages determine that the air-launched carrier vehicle is an important development direction [2]. In terms of the installation relationship between carrier rocket and carrier aircraft, it can be divided into internal type and external type, and external type is divided into back camel type and hanging type. Due to the exposure to the atmospheric environment, the thermal environment of the external air-launched carrier vehicle is relatively bad, which has an important impact on the reliability of the launch.

An external air-launched rocket relative to other on-load external objects, large volume, mass, not only in the design process is seriously limited to aircraft performance and transportation capacity, but also with the process of flight and launch to ensure the safety of the aircraft, this is the reliability of external air-launched rocket put forward high requirements. This paper analyzes the generating method of the reliability test profile of external rocket, generates the mission profile and environmental profile, and analyzes the environmental parameters of temperature stress, vibration stress, electric stress and humidity under different mission profiles. Finally, this paper corrects the test profile and gives the reliability of a comprehensive environmental test profile.

2. Generation Method of the Emission Reliability Test Profile

2.1. General Method for Reliability Test Profile Generation

The generation of the reliability test profile generally includes three parts:

First, the task profile was determined according to the user requirements. The task section is a temporal description of all the important events and states of the product during the whole life cycle of the completion of the specified task. It is the basis for determining the environmental profile of the product during the execution of the task. It depends on the user's requirements for the product, and is usually described in the form of task section characteristic parameter chart or characteristic parameter table. For external air-launched launch vehicles, there are three mission profile parameters: mission stage altitude (flight altitude of carrier platform), Mach number (flight speed of carrier platform) and duration of mission stage.

Second, the environmental profile was determined based on the task profile. Environmental profile refers to the relationship between environmental stress and time that will be encountered in actual use, mainly including temperature stress, mechanical (vibration) stress, humidity stress and electrical stress. The value of environmental stress is closely related to the characteristic parameters in the task profile. The purpose of a reliability test is to expose product faults and design defects, so the construction of an environmental profile should simulate the environment experienced by actual use as far as possible. The preferred order is measured stress, estimated stress, and reference stress.

Finally, the test profile is obtained by engineering treatment according to the environmental profile. It should be noted that although the relevant standards including GJB 899A Reliability Identification and Acceptance Test, emphasize the importance of measured stress [3], all measured stress cannot be realized in many cases. In engineering practice, in order to make the test section meet the standard requirements and make the product test as close to the actual environmental stress as possible, the preliminary design can be made according to the empirical data, and the subsequent section can be corrected according to the measured stress data.

2.2. Reliable Test Profile of Air-Launch Carrier Rocket

The external air-launched carrier rocket is generally installed under the belly of the plane or below the inner wing and is mainly composed of a payload, power system, control system, measurement system, and tile structure. Among them, the launch reliability level of the electronic products of the control system is directly related to the success or failure of the launch. However, due to the large scale and tonnage weight of the air-launched carrier rocket, it is difficult to carry out the full arrow test on the air-launched carrier rocket, and only the single-stage test can be carried out on the electronic products. According to GJB899 Annex B and the mission profile of an air-launched carrier vehicle, the reliability test profile of an air-launched carrier vehicle can be preliminarily constructed. Since the method mentioned in GJB899 is a general method applicable to a certain type of product equipment (combined external hang and air launch), the test profile should be corrected according to the actual situation of the tested product, such as the actual installation position and whether there is shock absorption, temperature regulation and so on.

3. Launch Mission Profile and Environmental Profile Generation

3.1. Mission Profile

The typical tasks of external air-launched carrier vehicle can be roughly divided into high-high launch and low-high launch [4]. High-high launch refers to the mission process in which the air-launched carrier rocket climbs to high altitude, and completes the launch preparation at high altitude. If the launch is suspended, it will follow the return, descent and landing. Low and high launch refers to the mission process in which the air-launched carrier rocket flies flat at low altitude, then climbs to high altitude and completes the preparation for launch. If the launch is suspended, the carrier will return, descend and land. In this paper, an electronic product of a typical air-launched carrier rocket is taken as an example.

3.2. Environmental Profile

3.2.1. Temperature Profile

At present, the understanding of temperature is basically consistent, namely that temperature is a function of height and Mach number [5]. According to the task profile of **Figure 1**, the temperature profile of high-high emission can be calculated theoretically, as shown in **Table 1**, and the temperature profile of low-high emission is shown in **Table 2**.

3.2.2. Vibration Profile

When the air-launched carrier rocket flies horizontally with the carrier platform, there are two main vibration-generating factors. One is the vibration response transmitted by the carrier platform to the carrier, mainly low frequency; the other is the vibration response generated by pneumatic noise excitation, mainly high frequency. The vibration profile of ordinary onboard external hanging objects can be calculated to determine the random vibration spectrum with a frequency range of 20 - 2000 Hz according to the formula recommended in GJB899A. As for the air-launched carrier rocket, its volume and weight are at the same level as the carrier. Under dynamic coupling with the carrier in the hanging state, the frequency is usually lower than 20 Hz, and the vibration difference of each part is large, so the vibration response cannot be described in the same condition. Therefore, the vibration profile needs to be corrected by simulation calculation and measured data.

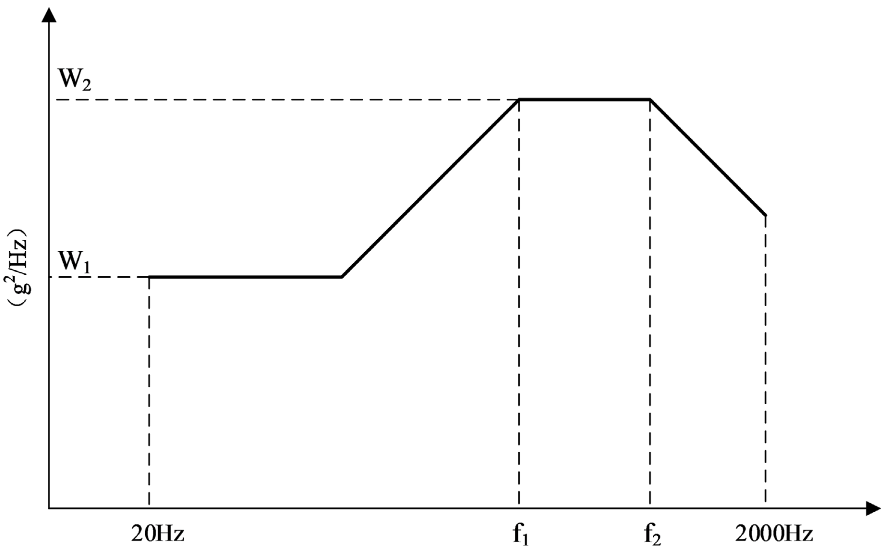

Figure 1. Emission-based reliability vibration profile.

Table 1. Low- and high-emission temperature profile (Unit: Celsius ˚C).

Action	Take off		Flat fly	Climb	Launch	Return	Descend	
Each time/min	0	10	82	10	20	80	16	–
Cumulative time/min	0	10	92	102	122	202	218	–
Launch site temperature	15	12	12	−22	−51	−49	−49	15
Temperature stress	15	25.72	32.13	−9.91	−33.79	−33.17	−37.37	15

Table 2. High- and high-emission temperature profile (Unit: Celsius ˚C).

Action	Take off	Flat fly	Climb	Launch	Return	Descend	
Each time/min	0	10	82	20	80	16	–
Cumulative time/min	0	102	92	122	202	218	–
Launch site temperature	15	−25	−49	−51	−49	−49	15
Temperature stress	15	−13.06	−33.17	−33.79	−33.17	−37.37	15

3.2.3. Humidity and Electrical Stress

In the emission reliability profile, the relative humidity is 60%, the first cycle applied voltage limit, the second cycle applied the nominal voltage, the third cycle applied voltage limit, three voltage changes constitute a complete electrical stress cycle, repeated the electrical stress cycle throughout the test process, this paper takes a product as an example, the nominal voltage 28 V.

4. Correct the Test Section in Engineering Based on the Measured Data

4.1. Correction of the Temperature Profile

When the environmental conditions are revised based on the measured data, it is best to obtain the direct environmental stress information of the tested product in the actual task profile. In the actual process of different launch tasks of air-launched carrier vehicles, sensors are generally installed in the typical positions inside the structure of the carrier rocket for measurement, and the curve is obtained after processing the measured data.

It can be seen that the measured data measured by the four temperature measuring sites are in good agreement with the trend of the theoretical calculation, but two corrections are made after comparison with the theoretical model:

In high-high launch missions, the coldest air temperature is corrected from −37.37 degrees to −35 degrees.

In the low and high launch missions, the air's hottest temperature was corrected from 32.13 degrees to 40 degrees.

The reason is that the large volume of air-launched carrier vehicle leads to large hot melting. Although the external temperature is low, it will not quickly pass inside the carrier rocket, and the friction effect and the suppression effect of the measured data are 2 - 3 degrees higher compared with the theoretical calculation data.

4.2. Correction of the Vibration Profile

The correction of the vibration profile should first obtain the measured data, that is, to carry out the external flight test of the air-launched carrier rocket. Low-frequency vibration and high-frequency vibration sensors are installed in each part of the carrier rocket, and the actual random vibration data processing of each mission section (different flight altitude, flight speed and flight duration) is measured to obtain the power spectrum density curve. The frequency domain data is treated with probability statistics (the normal one-sided tolerance upper limit statistical method is adopted), and the statistical expected power spectral density curve is obtained and smoothed. The vibration profile is corrected according to the measured statistical envelope curve to obtain the final vibration profile.

4.3. Comprehensive Engineering Section

After the correction of measured data and the ratio of low to high tasks, the comprehensive reliability profile of electronic equipment of air-launched launch vehicles is calculated.

5. Conclusion

This paper analyzes the generation method of the reliability test profile and analyzes the method of determining the environmental parameters of temperature stress, the environment and humidity of the test environment under different task profiles, corrects the experimental profile, and gives the reliability comprehensive test profile.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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