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Research on Reliability Evaluation Method of Multi - rotor UAV Airborne Controller

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Abstract. The reliability of multi-rotor Unmanned Aerial Vehicle (UAV) and the airborne controller is one of the research focus in UAV filed. In order to evaluate the reliability life of multi - rotor UAV airborne controller, this paper studied the basic principle of reliability life qualification firstly. Secondly, this paper focused on the analysis of the task profile of the multi-rotor UAV airborne controller, as well as the temperature, electricity and vibration stress of each task stage. Thirdly, the test profiles and specific parameters of each stress in the reliability test were determined. Lastly, some tests were done to verify the method proposed in the article. The reliability evaluation method of the multi - rotor UAV airborne controller proposed in this paper can be used in the practical application of UAV enterprises. It has good guiding significance.

1. Introduction

Common aircraft are usually divided into fixed wing, helicopter and multi-rotor (four rotor or six rotor is the mainstream). At present, the multi-rotor Unmanned Aerial Vehicle (hereinafter referred to as UAV) is widely used in civil and commercial use. People can use UAV to carry out aerial photography, express delivery, road mapping, disaster monitoring, agricultural plant protection, power inspection and other work. UAV has gradually become a part of people's daily life. Although the application of UAV is very wide, but due to the relatively less technology accumulation, the relatively weak key materials and processes and other reasons, the current domestic UAV in the process of carrying out the task, there are often some failures, which will affect the execution of the task, and will lead to the damage of parts or the whole machine of UAV, endangering personal and property safety. How to evaluate and improve the reliability of components and the whole UAV has become one of the important research contents in the UAV industry.

The main modules of multi-rotor UAV include flight platform, power device, navigation and flight controller, electrical system, communication system, necessary mission equipment and ground controller, etc. As shown in Figure.1. The sensors mainly include gyroscopes, accelerometers, magnetometers, barometers, GPS and so on, which are placed separately or integrated into the flight controller.

Due to the vibration, high temperature and other factors in the flight process of UAV, it will cause UAV failure. UAV faults can be roughly divided into software faults and hardware faults. There are two kinds of software faults: sensor data error and communication interruption. The solution of this kind of fault can only be realized on the basis of improving the fault tolerance and self-test function of the control program. Hardware failure can be divided into two categories: control system hardware failure

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and power system hardware failure. The types of control system hardware failure include sensor failure, single-chip or similar processor crash, pin damage, etc. the types of power system failure include motor abnormality, blade unexpected flying out and damage, motor drive abnormality and power system circuit abnormality (power supply abnormality of power system), etc. Most of these hardware faults can be identified by simulating the vibration, temperature and other multi stress tests of UAV in normal flight, so as to realize the reliability life assessment of multi rotor UAV. According to the basic principle of reliability, after the product is finalized, its inherent life will be determined accordingly. But how can the user of the product, such as the manufacturer of UAV, determine the reliability life of the product when purchasing the product to meet the requirements? Therefore, it is necessary to use the reliability identification method to identify the reliability life of products.

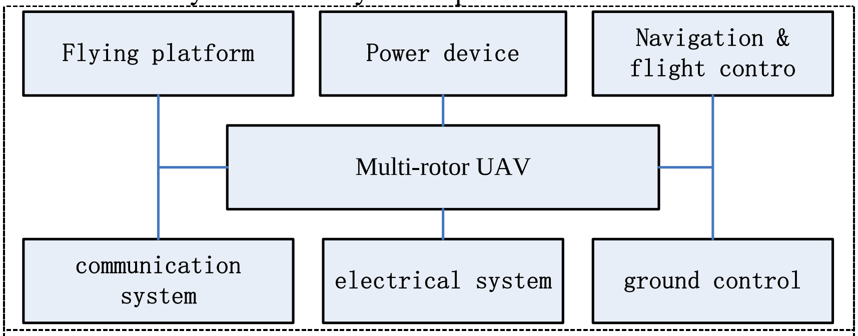

Figure 1. The main modules of multi rotor UAV.

Literature [1-3] studies the life of UAV body, literature [4-6] studies the reliability identification test scheme of UAV recording equipment, focusing on the analysis of the parameters selection in the reliability identification test scheme, such as test time t, sample number n, failure number r, manufacturer's risk α and user's risk β, as well as the determination method, and literature [7-8] Studies rotor UAV The fault safety system of UAV is studied, some common faults of UAV are given, and the fault detection and corresponding decision-making are studied, but the specific test methods and test sections for reliability evaluation of UAV airborne equipment are not involved. From the point of view of reliability life appraisal, this paper studies the whole process of reliability life appraisal scheme of airborne controller of rotorcraft, and focuses on the research and analysis of parameter selection method of test section, in order to provide enlightenment for reliability appraisal of airborne controller of rotorcraft.

2. Basic principle of reliability life assessment

It is assumed that the life distribution of UAV airborne equipment conforms to the exponential law, that is, the loss efficiency is constant. In reliability practice, this assumption is mostly satisfied for electronic products.

Because the reliability of the whole batch of products is judged by checking the reliability of the samples during the reliability appraisal test, there may be two types of errors: one is to criticize the qualified products as the unqualified products (the first type of errors); the other is to criticize the unqualified products as the qualified products (the second type of errors). The first type of error will cause loss to the producer, so the probability of the first type of error is the producer's risk ($\boldsymbol{\alpha}$); the probability of the second type of error is the user's risk ($\boldsymbol{\beta}$). When designing test plans, $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are usually between 5% and 30%.

When determining the reliability evaluation scheme, $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are negotiated by the manufacturer and the user, while the expected life MTBF value of the product is specified in the production contract. By selecting the appropriate upper limit ($\boldsymbol{\theta_0}$) and lower limit ($\boldsymbol{\theta_1}$) of MTBF inspection, the parameters in the evaluation scheme can be determined.

Take the statistical scheme of sequential test type reliability appraisal test as an example. For exponential products with unknown MTBF value $\boldsymbol{\theta}$, the probability of $\boldsymbol{r}$ failures in the accumulated working time $\boldsymbol{t}$ is:

$$P_r(r) = \left(\frac{t}{\theta}\right)^r \left(\frac{e^{-t/\theta}}{r!}\right) \tag{1}$$

If the actual MTBF of the product is equal to the lower limit of test θ_1 of MTBF, the probability of r failures within the working time t is:

$$P_1(r) = \left(\frac{t}{\theta_1}\right)^r \left(\frac{e^{-t/\theta_1}}{r!}\right) \tag{2}$$

If the actual MTBF of the product is equal to the upper limit of the inspection θ_0, the probability of r failures within the working time t is:

$$P_0(r) = \left(\frac{t}{\theta_0}\right)^r \left(\frac{e^{-t/\theta_0}}{r!}\right) \tag{3}$$

Let $P(r)$ be the ratio of the probability $P_1(r)$ when the MTBF value of the product is equal to the lower limit of test θ_1 of MTBF to the probability $P_0(r)$ when the MTBF value of the product is equal to the upper limit of test θ_0 of MTBF:

$$P(r) = \frac{P_1(r)}{P_0(r)} = (\frac{\theta_0}{\theta_1})^r e^{-[(1/\theta_1)-(1/\theta_0)]t} \tag{4}$$

During the test, the ratio was calculated continuously and compared with two predetermined constants A and B, using the following decision:

- If $P(r) < B$, receive the product and stop the test.
- If $P(r) > A$, reject the product and stop the test.
- If $B < P(r) < A$, continue the test.

Where the constants A and B are:

$$A = \frac{(1-\beta)(d+1)}{2\alpha d} \tag{5}$$

$$B = \frac{\beta}{1-\alpha} \tag{6}$$

Among them, α is the producer's risk, β is the user's risk, d is the identification ratio, that is, $d = \theta_0/\theta_1$.

During the test, if the failure failure number r is taken as the judgment basis, then

$$\frac{\ln B}{\ln(\theta_0/\theta_1)} + \frac{(1/\theta_1 - 1/\theta_0)}{\ln(\theta_0/\theta_1)}t < r < \frac{\ln A}{\ln(\theta_0/\theta_1)} + \frac{(1/\theta_1 - 1/\theta_0)}{\ln(\theta_0/\theta_1)}t \tag{7}$$

That is to say, when the value of failure number r is between the left and right sides of the inequality, the test will continue. If r is not greater than the left side, the acceptance judgment will be made and the test will be terminated; if r is not less than the right side, the rejection judgment will be made and the test will be terminated.

For the maximum test time T_0 in the qualification test scheme, it is derived from the estimated value of MTBF one-sided lower confidence limit:

$$T_0 = \frac{\theta_0 \chi^2_{(1-\alpha),2r_0}}{2} \tag{8}$$

r_0 is selected by the following formula:

$$\frac{\chi^2_{(1-\alpha),2r}}{\chi^2_{\beta,2r}} \geq \frac{\theta_1}{\theta_0} \tag{9}$$

Where, $\chi^2_{(1-\alpha),2r}$and$\chi^2_{\beta,2r}$ are the upper quantiles of the χ^2distribution with a degree of freedom of $2r$. Through the determined α, β and looking up the χ^2distribution table, we can get the values of the two until the ratio of the two values is not less than θ_1/θ_0, then the r value at this time is r_0.

3. Research on reliability test profile

After determining the parameter value of reliability qualification test, it is to develop appropriate test conditions (test profile) and carry out the test according to the selected reliability qualification test parameters.

In the reliability evaluation of UAV flight controller, the applied environmental stress includes electrical stress, vibration stress, temperature stress, humidity stress, etc. In order to make a comprehensive investigation, take the typical mission profile of rotorcraft, i.e. high altitude demonstration flight as an example, without external equipment, only to ensure the operation of the UAV's own equipment. During the operation, the ground control station is not included in the assessment scope. Accordingly, the mission profile of rotorcraft is formulated as shown in Figure.2:

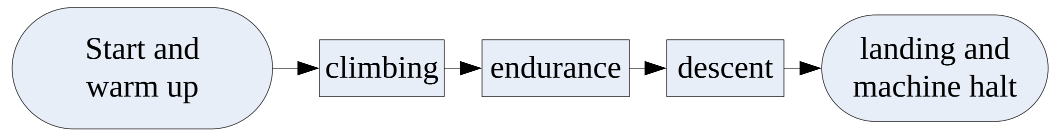

Figure 2. Mission profile of rotor UAV.

For the controller on the rotor UAV, its mission profile is consistent with the UAV body itself.

3.1. Electrical stress test profile

The electrical stress test profile of the UAV flight controller is generally applied according to the input voltage change requirements specified by the controller. If it is not specified in the equipment specification, the electrical stress of the flight controller can be considered to be cyclic variation with the amplitude of ± 10% of the nominal input voltage, i.e. the input voltage of the first test cycle is 110% of the nominal voltage; the input voltage of the second test cycle is the nominal voltage (UA); and the input voltage of the third test cycle is 90% of the nominal voltage. Among them, the third test cycle is used in start-up and warm-up phase, the first test cycle is used in climb phase, the second test cycle is used in cruise phase, and the third test cycle is used in descent, landing and shutdown phase. Corresponding to the task profile, the change of input voltage of multiple test cycles constitutes a complete electrical stress cycle. The test section is shown in Figure.3:

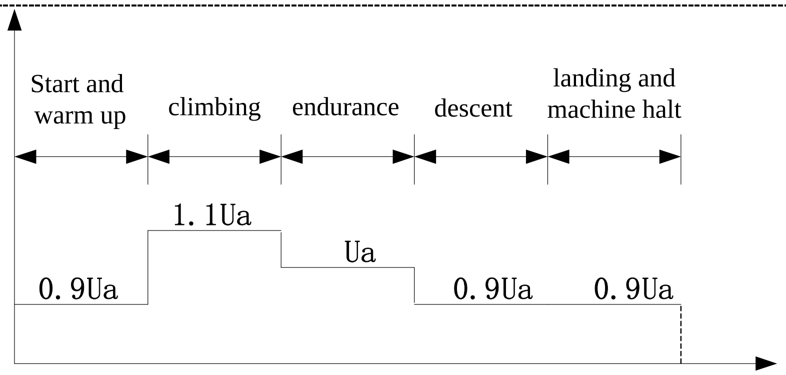

Figure 3. electrical stress test profile.

3.2. Vibration stress

The vibration characteristics of helicopter cargo transportation are the superposition of strong narrow-band peaks on the background of low-order continuous wide-band random vibration. This environment is a combination of many sinusoidal or nearly sinusoidal components caused by the main rotor, tail rotor and rotating machinery and low-order random components caused by the flow field. Figure 4 shows the vibration environment spectrum of the helicopter [9-10].

Because of the flight principle and structure principle of the current multi rotor UAV, the vibration generation is similar to that of the helicopter. Therefore, the vibration stress profile of the multi rotor UAV can be made according to the helicopter vibration environment. Considering the current use conditions of civil vibration equipment, it is determined that the continuous logarithmic scanning vibration of 5***Hz*** ~ 2000***Hz*** ~ 5***Hz*** is used. One scanning cycle of each axis of three axes is 36***min***, the maximum duration is 3***h***, and the maximum stress of the equipment is 50m/s^2. The rotorcraft is an equipment without shock absorber, and its test cycle is as follows:

The acceleration from 5***Hz*** to 33 ***Hz*** is ± 20 m/s^2, and the acceleration from 33 ***Hz*** to ***2000Hz*** is ± 50 m/s^2.

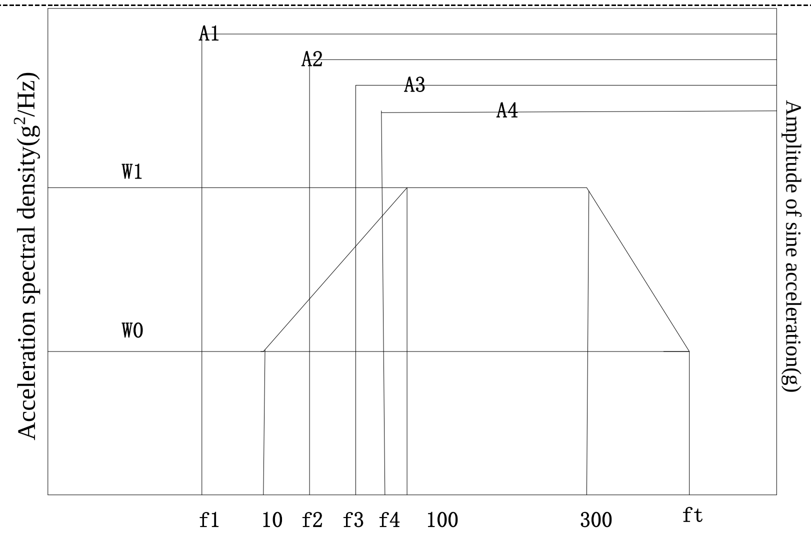

Figure 4. Spectrum of helicopter vibration environment.

3.3. Thermal stress

The temperature distribution data of a four rotor UAV (direct flight, low altitude 3***m***) is shown in Table.1:

Table 1. Flight test temperature data of a certain four rotor UAV.

Measuring position	Maximum temperature (℃)	Maximum temperature rise(***K***)
Shell (upper)	29.8	0.7
IMU Shell	36.6	7.5
Main control panel shell	35.1	6.0
Power chip shell	32.3	3.2
PCB	32.1	3.0
Motor housing	34.3	5.2
Shell (side)	29.6	0.5

Among them, the temperature of IMU inertial navigation module shell, main control board module shell and drive motor shell changes greatly, reaching 7.5 ℃, 6.0 ℃ and 5.2 ℃ respectively, and actually reaching 36.6 ℃, 35.1 ℃ and 34.3 ℃ (the ambient temperature is 29.1 ℃, and the relative humidity is 51% ***RH***). Considering the difference of ambient temperature in different regions, the standard temperature is adopted for the test, which meets the actual requirements and is more strict, that is, high temperature + 55 ℃, low temperature - 50 ℃.

3.4. Humidity stress

Humidity should be able to simulate warm and humid atmospheric conditions, especially the hot and humid conditions prevailing in tropical climate. The dew point in the test chamber shall be maintained at 31℃ or above during the hot soak stage and the ground working stage of the climate. In other stages, the dew point is not controlled, but the air in the test chamber cannot be dried.

4. Test verification

In order to verify the reliability life appraisal method of the airborne controller of the multi rotor UAV proposed in this paper, a certain type of four rotor UAV is selected for test. According to the test section studied in this paper, the test is carried out. Temperature, electric stress and vibration stress are combined into one test cycle, and humidity is not controlled. During the test, the output signal of the controller shall be monitored, including direction signal, throttle signal, indicator light, etc. [11]. Once there is an unrecoverable output abnormality, the onboard controller shall be judged as faulty and the life test shall be terminated. When the test lasts for 156h, the direction signal output of the controller is abnormal and there is continuous noise. It is determined that the fault occurs and the test is terminated. The reliability life of the airborne controller can be obtained by combining the relevant formula.

5. Conclusion

This paper studied the reliability evaluation method of the airborne controller of the multi rotor UAV, analyzed the basic principle of the reliability evaluation, and focused on the comprehensive environmental stress in the reliability evaluation test of the airborne controller, and finally carries out the test verification. The reliability evaluation method of the multi rotor UAV airborne controller proposed in this paper can be applied in the UAV enterprises, and can be extended to other applicable UAV products.

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